https://doi.org/10.17221/282/2021-PSE

Studying standard and rheological quality parameters of winter wheat by Python visualisation

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Citation: Magyar Z., Pepó P. (2021): Studying standard and rheological quality parameters of winter wheat by Python visualisation. Plant Soil Environ., 67.

Abstract: This study was carried out to present an innovative solution for interpreting large data sets in agri-statistics with the invocation of programmed visualisation. Moreover, the following polyfactorial long-term experiment embodies a comprehensive study of 18 wheat quality parameters. The effect of increasing dosages of fertiliser (control, N_{90}PK, N_{150}PK) was examined on 3 winter wheat cultivars (KG Kunhalom, GK Csillag, Hybiza) in two consecutive growing seasons (2018–2019). The ecological conditions of 2018 gave a significantly higher yield, meanwhile 2019 significantly augmented gluten spread, alveographic tenacity, alveographic deformation work, valorigraphic stability and quality group and loaf volume. N_{90}PK dosage was enough to realise yield and quality potential as well. Fertilising significantly improved 13 indices, namely yield, crude protein, Zeleny index, wet gluten content, alveographic extensibility, alveographic deformation work, valorigraphic water absorption, quality number and group, dough development time, stability, softening and loaf volume. Considering yield, cv. Hybiza performed better, while cvs. KG Kunhalom and GK Csillag possessed significantly better protein-linked postharvest attributes. One of the most important findings is that waffle chart, joint plot, correlation matrix and complexradar of Python provide a very powerful tool in agri-statistics. Also, the results can potentially improve the knowledge about cultivar-specific agronomy practice, wheat quality and the connections between these parameters.

Keywords: hybrid; over-fertilisation; crop year; well-adapted variety; RStudio

The quality of winter wheat flour has been a commonly researched field for many decades, due to its essential role in our daily diet. However, the continuous testing in long-term experiments is indispensable, because of the following facts: (1) the average lifetime of cultivars is constantly decreasing (Pepó and Sárvári 2011); (2) global warming trends, high frequency of abiotic stresses and extreme conditions; (3) last decades renewed the importance of good quality flour as a consequence of automatisation and frozen technology in the baking industry. In 2020, 24% of the global wheat production was sold in international trade (OECD 2020). Every year, 25–50% of the Hungarian wheat production is exported (Pepó and Sárvári 2011). In Hungary, hybrids appeared in public cultivation about 8 years ago and there is an increasing tendency of using them (Vida 2018).

It is well-documented that the quality of wheat is a genetically coded characteristics (Branlard et al. 2001), although it is undoubtedly necessary to choose the appropriate agronomy practice for realising its quality potential. However, next to adequate fertilisation, the quality group of the same cultivars can vary between A2-C1 because of the year-effect, stated by Horváth (2014), since the utilisation of fertilisers is influenced by weather conditions (Ayoub et al. 1994) and nutrient reactionary properties (Pepó 2011) as well.

According to Borghi et al. (1995), nitrogen fertiliser has a decisive impact on wheat quality. Above a certain threshold, increment of fertiliser dosage does not enhance statistically yield, and quality of winter wheat, either (Linina and Ruza 2018). Moreover, it can deteriorate gluten quality as well with the excessive

Supported by the Project No. EFOP-3.6.3-VEKOP-16-2017-00008, and is co-financed by the European Union and by the European Social Fund.

https://doi.org/10.17221/282/2021-PSE

Table 1. Fertilising treatments of the long-term experiment

Treatment	Time of application	N	P	K
		(kg/ha)		
Control (Ø)	–	–	–	–
$N_{90}PK$	autumn (basic fertilising)	45	67.5	79.5
	spring (top dressing)	45	–	–
$N_{150}PK$	autumn (basic fertilising)	75	112.5	132.5
	spring (top dressing)	75	–	–

augmentation of gliadin molecules (Borghi 1999). Fertilisation increased significantly loaf volume (LV) (Massoudifar et al. 2014) and alveographic tenacity (P) (Matuz et al. 2007) in previous experiments. Year and cultivar-effect exerted a strong influence on LV (Panozzo and Eagles 2000). In the study of Cho et al. (2018), loaf volume was in tight correlation with dough development time (DDT) (0.88**) and crude protein (0.85**).

Programming has reformed every aspect of our daily life. This paper addresses the following question: can programmed visualisation shed a new light on agri-statistics, can it present an innovative approach for making large data sets easier to understand and interpret?

MATERIAL AND METHODS

The experiment was carried out at the Látókép Experimental Farm (University of Debrecen) in two consecutive growing seasons (2018, 2019). The long-term experiment was set up in 1983, near Debrecen in Hungary (47°33'N, 21°27'E) in split-split plot design. The area belongs to calcareous Chernozem and loamy type and has medium organic carbon: 1.57–1.62%, medium P and K supply and near neutral pH (6.46). The forecrop was sweet corn.

The effect of three fertiliser levels was tested in 10 m^2 plots in 4 repetitions (Table 1). The 50% of N and the whole amount of the P and K were applied in autumn, the remaining 50% of the N fertiliser was applied in spring as top dressing (Table 2).

Following 3 winter wheat genotypes were tested: KG Kunhalom; GK Csillag (#1 winter wheat cultivar in Hungary between 2013–2016) and Hybiza (hybrid) (Table 3).

During the first phase, the wheat batches were treated by the SLN sample cleaner (Pfeuffer GmbH, Kitzingen, Germany), then samples were conditioned to 15.5% moisture content, lastly milled into flour with the Brabender Quadrumat Senior laboratory mill (MSZ 6367/9-1989). Crude protein (Kjeltec auto 2300, FOSS, Hilleroed, Denmark), wet gluten content (WGC) (ISO 21415-2, 2015, Glutomatic 2200, Perten Instruments, Waltham, USA), Zeleny index (MSZ EN ISO 5529, SediCom System, Lab-Intern Kft, Budapest, Hungary), gluten index (GI) (ISO 21415-2, 2015), Hagberg falling number (HFN) (ISO 3093, 2009, Perten 1500, Perten Instruments, Waltham, USA), baking test (MSZ 6369/8-1988, QA 226, Labor MIM, Budapest, Hungary), valorigraph (MSZ ISO 5530-3, 1995, QA 205, Labor MIM, Budapest, Hungary) and alveograph (ISO 27971, 2015, MA 87, Chopin, France) parameters were defined at the Institute of Food Engineering, University of Szeged.

For data management, RStudio 3.6.1 version (Boston, USA) and Python 3.7 version (Wilmington, USA) were used. One-way ANOVA with *LSD* (least significant difference) post-hoc tests on $P > 0.05$ significance level of RStudio's package "agricolae" (Mendiburu 2019) and PCA of Python were performed. According to Tóthné (2011) there are very tight, tight and medium correlations if the correlation coefficient is between 0.9–1, 0.75–0.9 and 0.5–0.75, respectively. For graphical representation Matplotlib library (for complexradar, correlation matrix, waffle chart, heatmap) and Seaborn library (for joint plot) were used (Hunter 2007, Waskom et al. 2020).

Table 2. Agronomic details of the experiment

Growing season	Sowing date	Basic fertilising	Top dressing	Harvest date
2017/2018	04. 10. 2017	02. 10. 2017	12. 04. 2018	05. 07. 2018
2018/2019	05. 10. 2018	20. 09. 2018	20. 03. 2019	09. 07. 2019

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Table 3. Main information of the studied cultivars

Cultivar	Year of registration	Breeder	Maturity	Quality
KG Kunhalom	2002	University of Debrecen	medium	excellent
GK Csillag	2005	GabonaKutató Kft.	early	good
Hybiza	2015	Saaten-Union	early	milling

The first season was rainy (total precipitation: 642.4 mm, Figure 2), the second was normal (465.1 mm) in comparison with the 30-year average (493.9 mm), but in both seasons (2018: 10.3 °C, 2019: 10.4 °C, Figure 1) the average temperature was higher by 1 °C, compared to the 30-year average (9.3 °C). To summarise, the weather of both growing seasons was suboptimal for the vegetative and generative development of wheat plants.

RESULTS AND DISCUSSION

Examining the year-effect, it can be concluded that 2018 gave a significantly higher yield (+ 1 595 kg/ha) than 2019; however, in the case of gluten spread, stability (+ 1.1 min), P, alveographic deformation work (W) and LV (+ 81.3 cm^3), the ecological conditions of 2019 were significantly more favourable (Tables 4–5). These values correlate well with the findings of Ayoub et al. (1994), Panozzo and Eagles (2000).

Observable differences could be noted between the studied cultivars, namely: KG Kunhalom possessed significantly better Zeleny index, wet gluten content (WGC), valorigraphic quality number, DDT, stability, softening, L, W and loaf volume compared to other cultivars. In addition, cvs. KG Kunhalom and GK Csillag had considerably higher CP, gluten spread, HFN, water absorption and loaf form ratio than cv. Hybiza. These results are in line with the statements of Pepó (2011). As far as cv. Hybiza is concerned as the only hybrid, it shows a poor figure concerning quality parameters, also it possesses too strong gluten, which results in low loaf volume despite the fact that it had an observably good yield. This suggests that hybrids are unsuitable for baking use, but can be a good source of animal feed.

In the case of yield, crude protein (CP), Zeleny index, WGC, valorigraphic water absorption, quality number, DDT, stability, softening, L, W and loaf volume, the usage of fertilisers significantly improved the parameters in contrast with control samples. The following exceptions were recorded: HFN, P and loaf form ratio, which does not support the observations of Matuz et al. (2007). In every instance, N_{90}PK dosage was enough to realise the quality potentials. This is in complete agreement with Borghi et al. (1995), Massoudifar et al. (2014), and Linina and Ruza (2018).

Waffle diagrams present an informative way for interpreting the results of valorigraphic quality group, as shown in Figure 3. It can be concluded that in 2018, 53% of the samples were of feed quality (C2–C1), 47% were of milling quality (B2–B1), however in 2019, 25% of the samples were of feed quality (C2–C1), 75% were of milling quality (B2–B1), which highlights that the conditions of 2019 were much favourable for quality parameters, which also confirms the previous findings of Horváth (2014). Scrutinizing the effect of

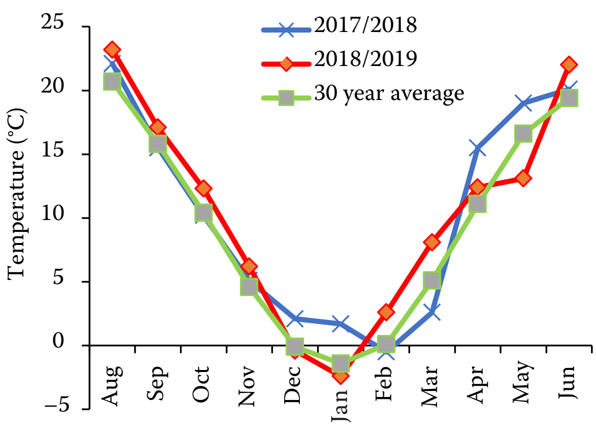

Figure 1. Temperature data of the experiment

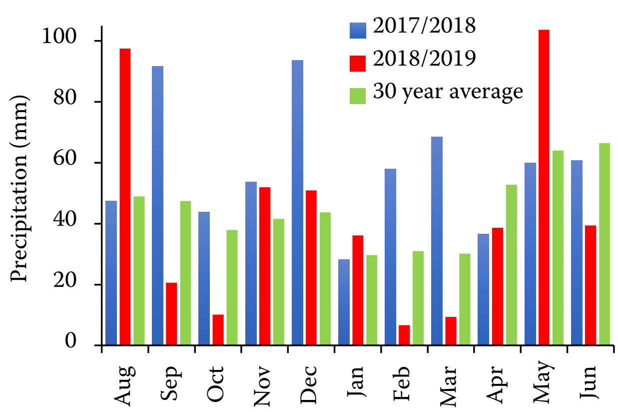

Figure 2. Precipitation data of the experiment

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Table 4. Results of the standard methods (2018–2019)

Yr	Cv	Tr	Y (kg/ha)	CP (%)	ZI (cm^3)	WGC (%)	GS (mm)	HFN (s)	GI (%)	LFR	LV (cm^3)
2018	GK Csillag	Ø	6 417	9.7	23.7	20.7	1.6	356	65.7	2.15	895
		$N_{90}PK$	8 267	12.8	34.9	29.7	5.3	379	35.8	2.26	940
		$N_{150}PK$	8 759	13.5	35.8	31.8	5.8	379	36.1	2.51	914
	KG Kunhalom	Ø	5 829	10.7	32.6	24.3	3.6	369	56.9	2.23	833
		$N_{90}PK$	7 617	13.8	42.5	34.0	4.2	370	44.3	2.43	993
		$N_{150}PK$	7 154	14.4	45.2	34.8	4.4	390	43.1	2.27	1 043
	Hybiza	Ø	7 569	7.9	23.8	16.8	0.4	329	96.1	1.95	768
		$N_{90}PK$	9 172	10.1	33.0	22.0	0.8	296	95.4	2.09	840
		$N_{150}PK$	8 879	10.5	35.1	23.2	0.8	290	93.2	2.14	863
2019	GK Csillag	Ø	4 560	10.6	25.2	22.2	0.3	387	93.1	2.05	904
		$N_{90}PK$	6 686	13.5	32.0	31.0	1.4	399	65.7	2.10	1 016
		$N_{150}PK$	6 485	13.4	31.8	31.4	2.3	395	62.6	2.05	1 005
	KG Kunhalom	Ø	4 894	11.9	36.4	27.9	1.9	344	71.5	2.07	1 003
		$N_{90}PK$	6 539	13.2	38.4	31.8	2.9	326	55.6	1.96	1 073
		$N_{150}PK$	7 020	13.4	38.4	33.0	3.2	319	51.4	2.06	1 073
	Hybiza	Ø	5 389	6.9	26.2	17.6	0.3	320	98.4	1.90	903
		$N_{90}PK$	6 927	8.7	30.9	21.1	0.6	342	98.3	1.94	928
		$N_{150}PK$	6 806	9.1	32.5	21.5	0.7	337	97.4	2.01	915
Average value of 2018:			7 740	11.5	34.1	26.4	3.0	351	63.0	2.23	898
Average value of 2019:			6 145	11.2	32.4	26.4	1.5	352	77.1	2.02	980
Average value of control (Ø):			5 776	9.6	28.0	21.6	1.4	351	80.3	2.06	884
Average value of $N_{90}PK$:			7 535	12.0	35.3	28.3	2.5	352	65.9	2.13	965
Average value of $N_{150}PK$:			7 517	12.4	36.5	29.3	2.9	351	64.0	2.17	969
$LSD_{0.05}$ (Yr):			1 045	1.1	2.8	2.8	0.8	16.8	10.7	0.08	38.5
$LSD_{0.05}$ (Cv):			1 615	1.0	3.5	2.9	1.0	13.9	10.7	0.11	49.5
$LSD_{0.05}$ (Tr):			1 323	1.1	2.8	2.8	1.0	20.6	13.2	0.12	48.3

Yr – year; Cv – cultivar; Tr – treatment; Y – yield; CP – crude protein; ZI – Zeleny index; WGC – wet gluten content; GS – gluten spread; HFN – Hagberg falling number; GI – gluten index; LFR – loaf form ratio; LV – loaf volume; *LSD* – least significant difference

fertilising, the diagrams reveal that, next to control treatment, 58% of the samples were of feed quality (C2–C1) and 42% were of milling quality (B2–B1). In the case of $N_{90}PK$ dosage, 25% of the samples were of feed quality (C2–C1) and 75% were of milling quality (B2–B1), nevertheless analysing the data of $N_{150}PK$ dosage, 33.3% of the samples were of feed quality (C2–C1), 66.7% were of milling quality (B2–B1). This can provide additional confirmation about the possibility of over-fertilisation; in other words, $N_{90}PK$ was enough to realise quality potentials.

One of our main goals was to create a complex solution for analysing wheat quality parameters. Figure 4 presents the ComplexRadar, which is able to provide useful and easily understandable information with the usage of 10 parameters, which were chosen to cover a wide spectrum of attributes, including the most crucial ones, like gluten quantity (WG) and quality (GI and ZI), α-amylase activity (HFN), kneading properties (DDT), water absorption (WA), strength (ST) and extensibility of dough (W and P/L), also baking test (LV). The selection of parameters and value limits were determined with the support of the Hungarian wheat standard and the Pannon wheat standard (Bedő 2008). The tendencies of different cultivars, growing seasons and nutrient supplies can be clearly seen. Comparing the two years, it can be observed that next to control treatment, the area of coloured decagons in 2019 is appreciably larger. In addition, in the case of GK Csillag and Hybiza, 2019

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Table 5. Results of the rheological measurements (2018–2019)

Yr	Cv	Tr	P (mm)	L (mm)	P/L	W ($\times 10^{-4}$ J)	VWA (%)	VQN	DDT (min)	ST (min)	DS (VE)
2018	GK Csillag	Ø	84	61	1.43	157	58.6	39.7	1.4	5.3	143
		$N_{90}PK$	77	103	0.75	197	61.8	48.0	4.1	6.3	144
		$N_{150}PK$	67	107	0.63	179	62.3	47.3	4.1	5.9	146
	KG Kunhalom	Ø	59	98	0.62	158	58.2	49.0	3.3	7.3	131
		$N_{90}PK$	62	142	0.44	209	62.2	55.8	4.6	6.6	114
		$N_{150}PK$	68	139	0.50	235	62.5	59.6	5.4	7.6	105
	Hybiza	Ø	70	54	1.38	133	52.8	31.7	1.0	2.6	150
		$N_{90}PK$	81	82	0.99	221	54.5	40.1	1.0	5.1	130
		$N_{150}PK$	81	75	1.08	211	54.6	42.5	1.3	5.4	123
2019	GK Csillag	Ø	97	64	1.51	208	60.6	41.2	1.5	6.0	145
		$N_{90}PK$	101	96	1.05	290	63.7	52.0	4.4	7.1	138
		$N_{150}PK$	99	98	1.01	286	63.7	51.9	4.4	6.9	138
	KG Kunhalom	Ø	78	114	0.69	251	59.0	50.2	4.8	7.4	148
		$N_{90}PK$	73	122	0.60	240	61.2	60.3	4.5	7.8	121
		$N_{150}PK$	64	136	0.48	233	61.6	58.3	4.6	7.9	115
	Hybiza	Ø	81	56	1.47	165	54.7	41.8	1.6	5.3	135
		$N_{90}PK$	79	88	0.90	221	55.3	47.2	1.9	6.8	123
		$N_{150}PK$	84	76	1.12	216	55.3	44.5	2.0	6.5	133
Average value of 2018:			72	96	0.87	189	58.6	46.0	2.9	5.8	132
Average value of 2019:			84	95	0.98	234	59.5	49.7	3.3	6.8	133
Average value of control (Ø):			78	74	1.18	179	57.3	42.3	2.3	5.6	142
Average value of $N_{90}PK$:			77	106	0.77	227	59.9	50.4	3.4	6.5	129
Average value of $N_{150}PK$:			77	105	0.80	227	60.0	50.7	3.6	6.7	126
$LSD_{0.05}$ (Yr):			5.2	13.7	0.18	19.0	1.7	3.9	0.8	0.7	7.8
$LSD_{0.05}$ (Cv):			7.0	16.3	0.22	26.1	1.2	4.7	0.9	0.8	9.3
$LSD_{0.05}$ (Tr):			7.2	14.9	0.2	23.8	2.0	4.4	0.9	0.8	8.8

Yr – year; Cv – cultivar; Tr – treatment; P – alveographic tenacity; L – alveographic extensibility; P/L – ratio of tenacity and extensibility; W – alveographic deformation work; VWA – valorigraphic water absorption; VQN – valorigraphic quality number; DDT – dough development time; ST – dough stability; DS – dough softening; *LSD* – least significant difference

gave an observably bigger area of decagons next to fertilising as well. Also, fertilising significantly augmented the areas of decagons in contrast with control treatments, but the difference between $N_{90}PK$ and $N_{150}PK$ dosages is inconspicuous; this can suggest that the second fertiliser dosage may not have any significant improving effect.

The results of the PCA can be seen in Figure 5, during interpretation, only those values were concerned, which had at least ± 0.5 correlation coefficient. Fertilising was in medium correlation with yield, crude protein, Zeleny index and WGC.

Considering the protein-related parameters, CP was in a very tight relationship with wet gluten; in tight with Zeleny index, valorigraphic water absorption, quality number, DDT and L; in medium correlation with gluten spread, stability, W and loaf volume. In addition, CP correlated in a negative way with gluten index and P/L. The key role of crude protein in baking quality is shown nicely in PCA, since 67% (18/12) of the studied parameters were at least in medium correlation with crude protein, also it was in an essential relationship with every rheological characteristic. Wet gluten content is also a decisive attribute in the Hungarian wheat standard, which was also strengthened by our results since 67% of the studied attributes were at least in medium relationship with WGC. Wet gluten content was in

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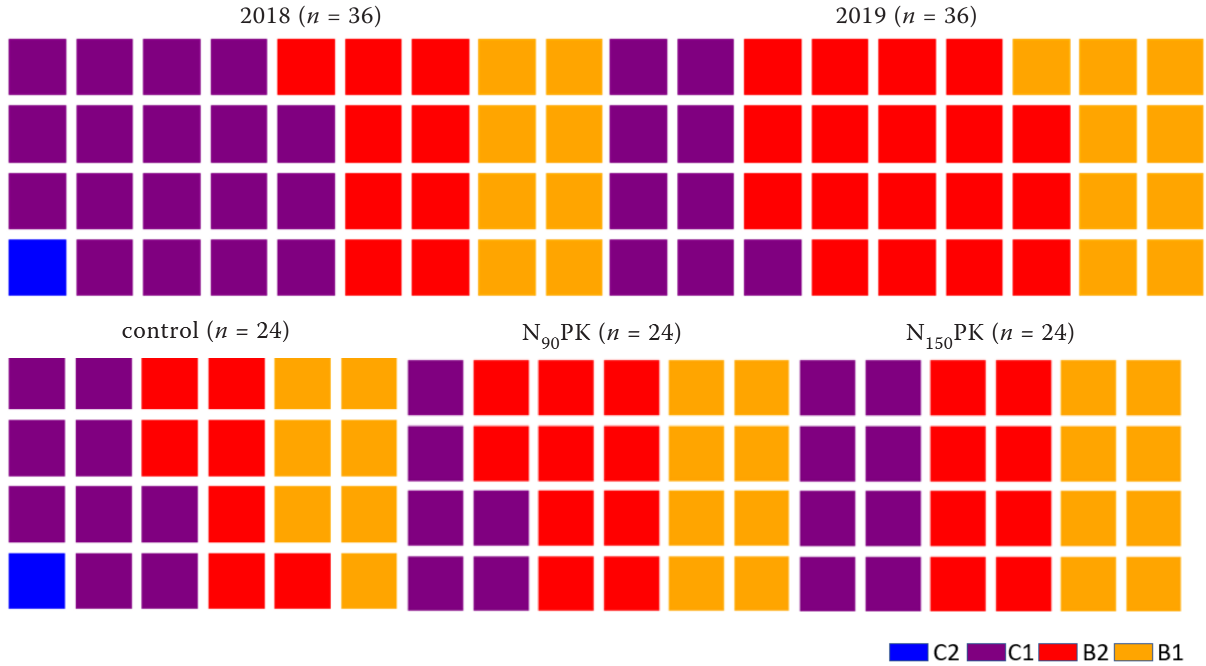

Figure 3. Effect of year and fertiliser on valorigraphic quality group. C2–C1 – feed quality groups (C2 if VQN is 0–29.9; C1 if VQN is 30.0–44.9); B2–B1 – milling quality groups (B2 if VQN is 45.0–54.9; B1 if VQN is 55.0–69.9) (MSZ ISO 6369-6, 2013)

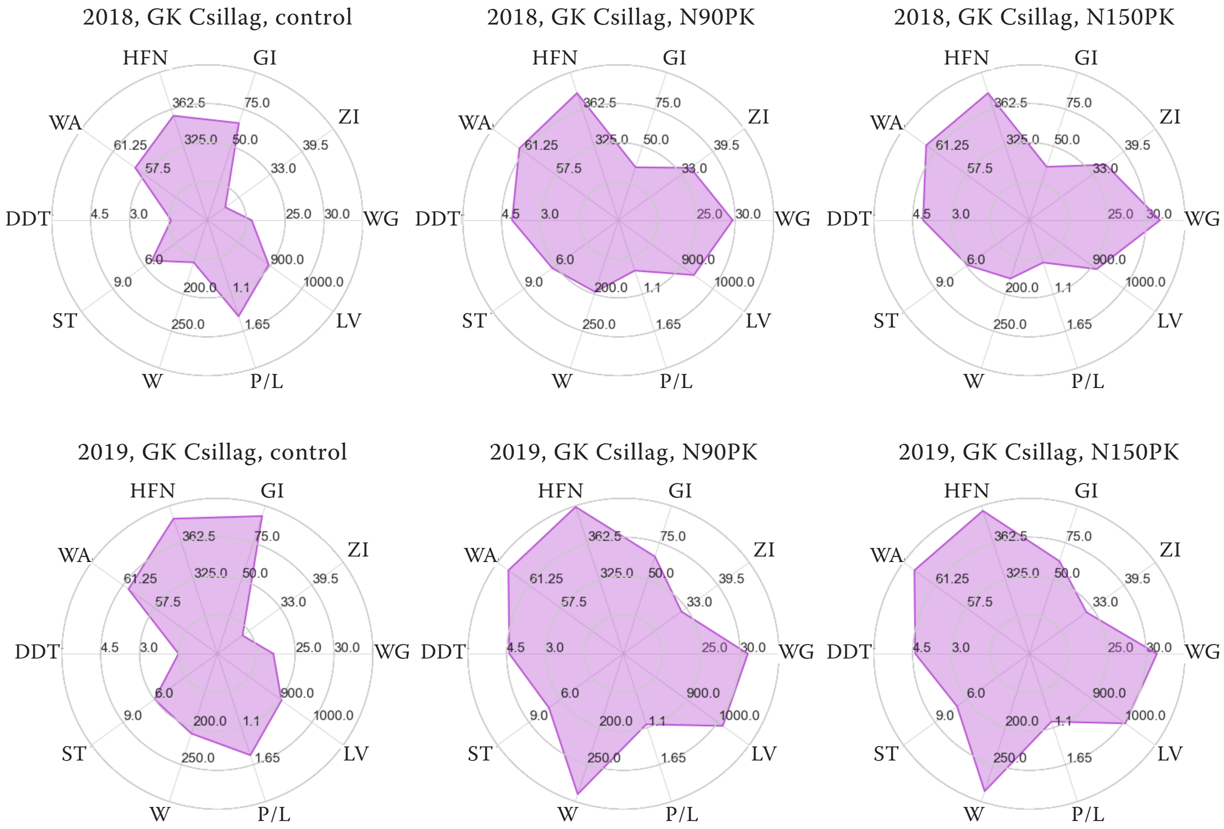

Figure 4. ComplexRadars of the studied cultivars. An explanation of all the abbreviations used is on the following page

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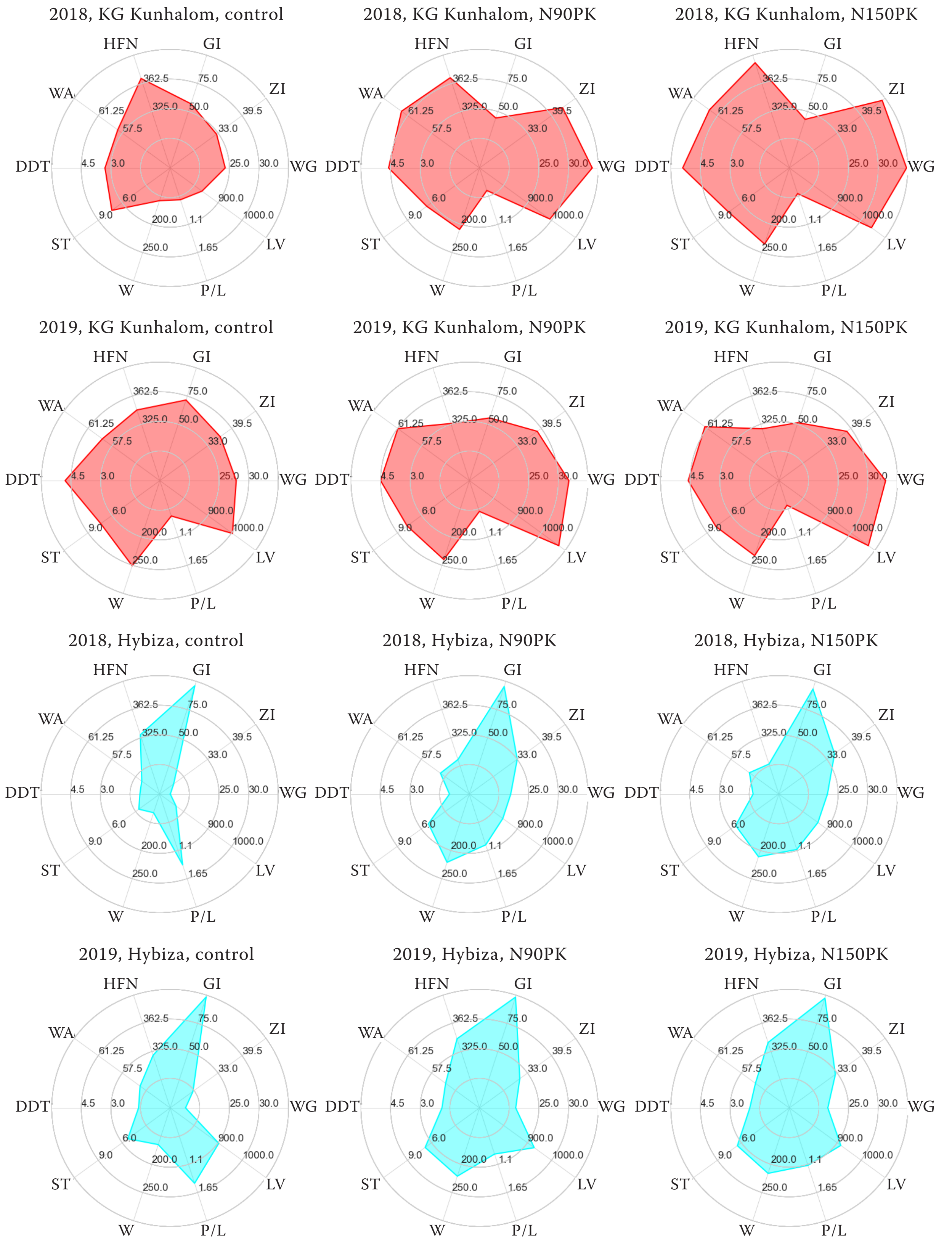

Continued Figure 4. HFN – Hagberg falling number; WA – water absorption; DDT – dough development time; ST – dough stability; W – alveographic deformation work; P/L – ratio of tenacity and extensibility; LV – loaf volume; WG – gluten quantity; ZI – Zeleny index; GI – gluten index

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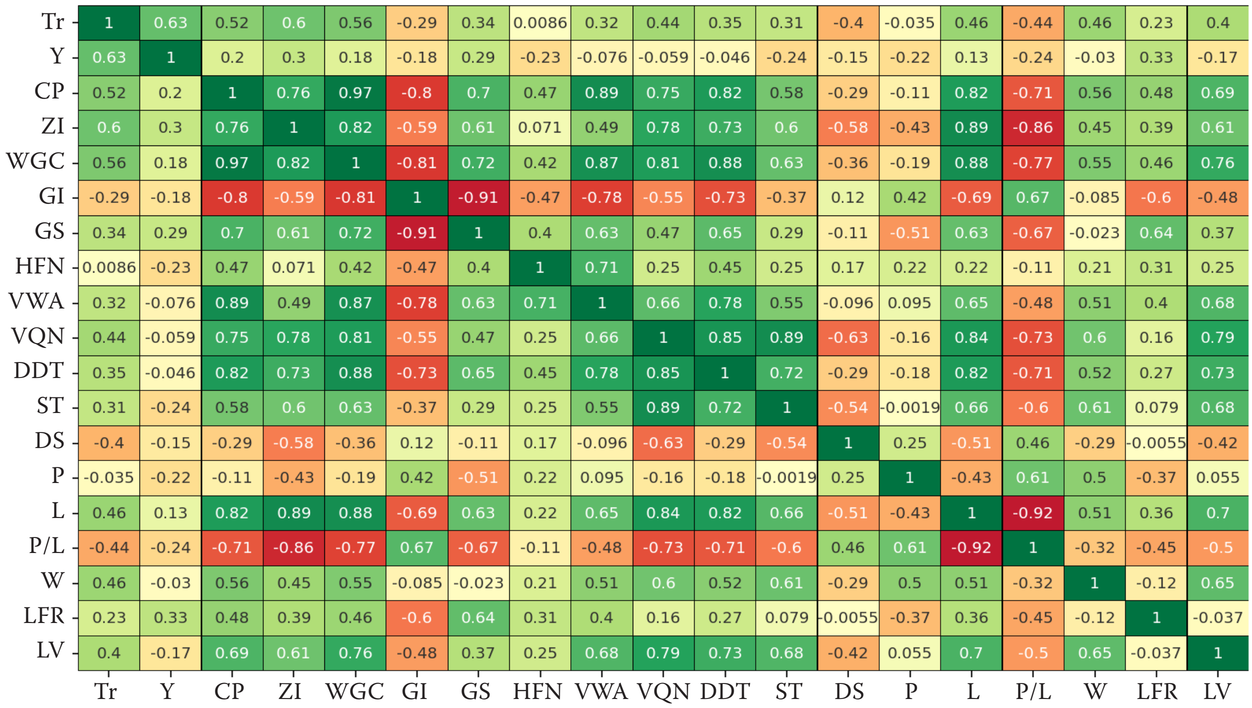

Figure 5. Pearson correlation matrix. Tr – treatment; Y – yield; CP – crude protein; ZI – Zeleny index; WGC – wet gluten content; GI – gluten index; GS – gluten spread; HFN – Hagberg falling number; VWA – valorigraphic water absorption; VQN – valorigraphic quality number; DDT – dough development time; ST – dough stability; DS – dough softening; P – alveographic tenacity; L – alveographic extensibility; P/L – ratio of tenacity and extensibility; W – alveographic deformation work; LFR – loaf form ratio; LV – loaf volume

very tight correlation with CP (0.97**); in tight with ZI, valorigraphic water absorption, quality number, DDT, loaf volume and L; in medium with gluten spread, stability and W; and in negative, tight with GI and P/L. The relationship of WGC with L, gluten spread and gluten index suggests that the higher the

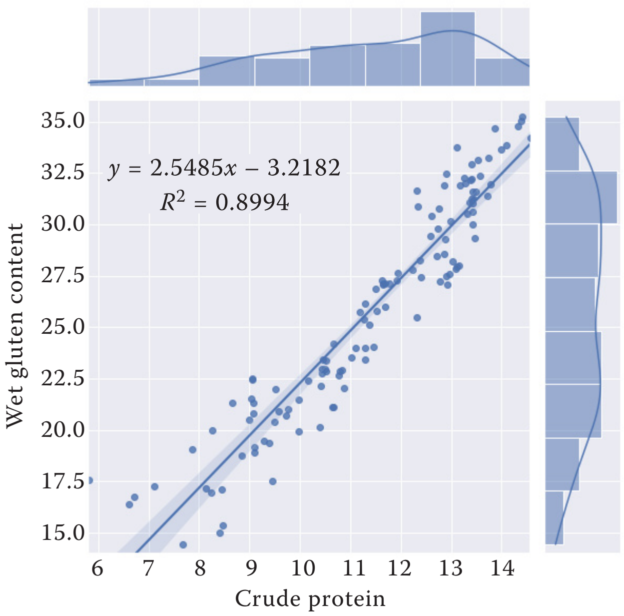

Figure 6. Linear regression of wet gluten content and crude protein

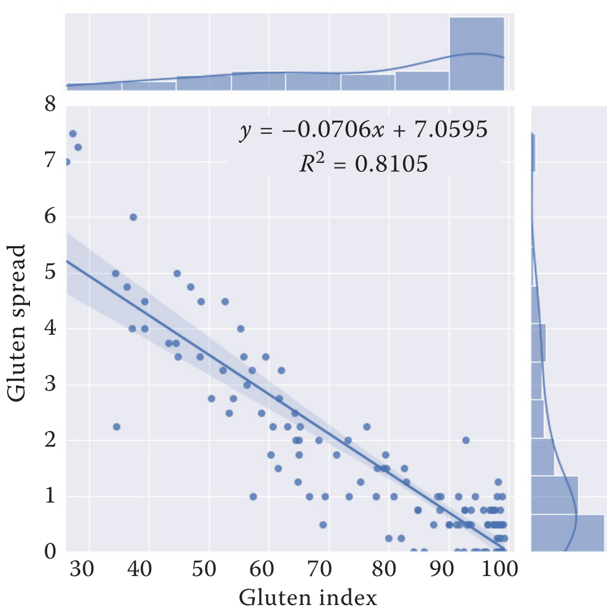

Figure 7. Linear regression of gluten spread and gluten index

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WGC is, the more ductile the dough will be. This phenomenon can be explained by the conclusions of Borghi (1999), that above a certain WGC, the ratio of glutenin/gliadin can change significantly in favour of gliadin. Because of the clear correlation (Figure 5) and regression (Figure 6) between wet gluten and crude protein content, in the Complexradars WGC was used, since the method of glutomatic is faster and more informative. Zeleny index was in tight correlation with crude protein, WGC, VQN, and L; in medium with gluten spread, DDT, stability and loaf volume; however, in negative with P/L, gluten index and dough softening.

Gluten index was in a tight, negative relationship with GS (–0.91**), VWA, wet gluten and CP; in medium with Zeleny index, DDT, L, loaf form ratio and VQN, but in positive with P/L. Because of the correlation (Figure 5) and regression (Figure 7) between gluten index and gluten spread (R^2 = 0.831), in the ComplexRadars gluten index was used, since the results of gluten index are much more precise and faster.

Considering the results of rheological methods, valorigraphic water absorption was in medium, significant correlation with gluten spread, HFN, VQN, stability, W, loaf volume and L; in tight relationship with crude protein, DDT and wet gluten, but in negative with gluten index. Quality number correlated tightly with L, CP, loaf volume, DDT, Zeleny index and WGC. Meanwhile, VQN was in a moderate, positive relationship with W and VWA. Quality number was in a negative relationship with gluten index and P/L. Dough development time was in a tight correlation with WGC, CP, water absorption, quality number and L; in perceptible with stability, Zeleny index, gluten spread, W and loaf volume; but in moderate, negative with GI and P/L. The above-mentioned data suggest that the higher the protein quantity is, the more time is needed for the dough to develop appropriately. It can be stated that a negative relationship could be realised between stability and P/L. Stability was in a moderate, positive correlation with CP, Zeleny index, WGC, valorigraphic water absorption, DDT, L, loaf volume and W. Valorigraphic dough softening was in a medium, negative relationship with L and Zeleny index.

Scrutinising the results of alveograph, it can be concluded that P was in a medium relationship with W; but in negative with GS. L was in a medium, negative correlation with GI and DS; in tight, positive with CP, Zeleny index, WGC, quality number, DDT; in medium with gluten spread, VWA, stability, W and loaf volume, which indicates that to achieve high-volumed loaves, the dough has to be ductile and stable. Meanwhile, a tight, negative correlation was recorded between P/L and ZI; medium with crude protein, WGC, gluten spread, VQN, DDT, stability and loaf volume; but positive, medium with gluten index. W was in perceptible correlation with crude protein, WGC, water absorption, quality number, DDT, stability, L, loaf volume and P.

Studying the outcome of baking tests, it can be noted that loaf form ratio was in medium correlation with gluten spread; in negative medium with gluten index. Loaf volume was in medium relationship with CP, WGC (0.76**), Zeleny index (0.61**), VWA, VQN (0.79**), DDT, stability, L (0.7**) and W (0.65**); in negative with P/L (–0.5**); the results prove that large volumed loaf can only be made from flour that possesses good protein and ductile dough parameters. Our results provide additional evidence for the statement of Cho et al. (2018) about the correlations of loaf volume.

As a conclusion, to the best of our knowledge, these features of Python altogether have not been used so far in agricultural sciences. One of the most important findings is that waffle chart (for presenting VQG), joint plot (for regression analysis), heatmap (for PCA) and Complexradar (for complex quality analysis) of Python provide a very powerful tool in agri-statistics and they can be applied in various fields of science. Also, these results underline the importance of cultivar-specific nutrient supply and the selection of well-adapted cultivars in order to avoid over-fertilisation next to maximising yield and quality of winter wheat production.

Acknowledgement. This research was funded by the EFOP-3.6.3-VEKOP-16-2017-00008 project. The project is co-financed by the European Union and the European Social Fund. We are grateful to Cereal Research Non-profit Ltd. and the University of Szeged, Faculty of Engineering for providing the instruments, also to Látókép Experimental Farm, University of Debrecen for providing the wheat samples. We would like to express our deepest appreciation to Mónika Bakos Tiborné and Tamás Magyar for assistance in performing the measurements and programming.

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Received: June 1, 2021
Accepted: November 15, 2021
Published online: December 1, 2021