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From farm to fork: evaluation of 143 different emmer varieties on agronomic, flour and quality traits in comparison to wheat, spelt and durum

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Summary

Consumers are increasingly interested in products made with ancient grains. We therefore investigated 143 varieties of emmer with leading varieties from common wheat, durum wheat, spelt and einkorn in multiple locations. A central project outcome was the development of a standard milling and baking trial for emmer. Although emmer is cultivated only on few thousand hectares, the variability within emmer varieties is high regarding all evaluated traits. For instance, the raw yield of the different emmer varieties ranged from 34 to 80 dt/ha. Compared to common wheat, emmer has on average a lower grain yield, higher risk to lodging and yellow rust infection, higher protein content, lower sedimentation volume, lower dough stability, lower extensibility, higher water absorption and lower retrogradation. The different dough properties of emmer must absolutely be considered for baking trials with emmer and the judgment of baking quality should include loaf volume and height/width ratio of the bread. Sedimentation volume correlated quite well with baking quality, while protein content did not. In current emmer supply chains, the choice of varieties should mainly address high yield with low farming risk and practical bakers should adapt recipes to emmer-specific properties to realize premium products.

Emmer – a cereal with a long tradition

Emmer (*Triticum turgidum* ssp. *dicoccum*) is one of the oldest cereals humans use. Like einkorn or spelt, it belongs botanically to the large wheat family. Emmer originally comes from the Fertile Crescent, the region between the Euphrates and Tigris rivers in present-day Syria and Iran. It was particularly important to the Egyptian pharaohs. Until the Middle Ages, emmer was widespread in Europe, but was then displaced by the higher-yielding species spelt and wheat. The emmer varieties, still available today from gene banks, are at most 100 years old, rather younger.

Like spelt, emmer is a hulled wheat, which means that the grain is firmly enclosed in the hulls and remains in it when harvested. The combination of grain and hull is called spikelet. A further working step in the mill is required to separate the kernels from the hulls. Currently, emmer is only grown on a small scale, but the demand for ancient

products and raw material alternatives to wheat is increasing - almost faster in the hobby baking sector than among professionals. In first field studies, we found that emmer can be grown well in Central Europe (Longin et al. 2016). This study also showed that emmer has a very hard grain, higher protein and gluten content but a different gluten composition than wheat (Geisslitz et al. 2019). In addition, it is known that emmer cannot be processed classically like wheat, but recipes should be adapted mainly by using less kneading energy and longer dough proving time (e.g., Ringer and Börsmann 2016).

These studies are all based on a small number of emmer varieties, although there are several hundred of them stored in gene banks around the world. We therefore launched a research project together with Pflanzenzucht Oberlimpurg, the Südwestdeutsche Saatzucht GmbH & Co. KG and the Detmold Institute for Grain and Fat Analysis (DIGeFa). We collected several hundred emmer varieties from various gene banks and propagated them over several years. In the multiplications, we then selected the agronomically better varieties and additionally added several dozen new emmer varieties from the market to test a total of 143 emmer varieties across multiple locations in the field and laboratory. The aims of these extensive trials were to (1) assess the variability of emmer varieties in agronomic characteristics as well as important quality traits, (2) develop suitable milling and baking trials for emmer, (3) investigate possible rapid methods for quality determination in emmer, and (4) develop tips for processing emmer into premium products.

Material & Methods

We compared 143 different varieties of winter emmer with reference varieties from wheat (Genius, Julius), spelt (Zollernspelz, Franckenkorn), durum (Sambadur, Wintergold) and einkorn (Terzino) in yield plot trials (>5m² area per plot). The trials were grown on four conventionally farmed locations in a p-rep design (locations: 70599 Stuttgart-Hohenheim in 2020 (Fig. 1), 72813 St. Johann in 2020, 74523 Schwäbisch Hall in 2019 and 76437 Rastatt in 2019). Herbicides, growth regulators, and fungicides were used in conventional cultivation, but nitrogen fertilization was reduced by approximately 65% compared to wheat at all locations. In these trials, susceptibility to yellow rust and lodging (scores: 1 = lowest, 9 = highest) were recorded in addition to raw yield (dt/ha). The harvested samples were used for quality analysis. All samples were dehulled and cleaned. Protein content (NIRS, ICC standard method 159), sedimentation value (with sodium dodecyl sulfate; ICC standard method 151) as well as kernel yield (weight after dehulling and cleaning in % to raw harvest weight) were determined.

First, at DIGeFa, a standard milling test was developed for emmer. The aim was to achieve the highest possible flour yield of a type comparable to spelt flour of type 630. Using these flours, various dough properties were then evaluated using mixolab (ICC standard method 173) and extensograph (ICC standard method 114/1). In addition, a

standard baking test for emmer was developed on preliminary samples of a few emmer varieties. Based on the mixolab kneading curves, we identified that emmer should be kneaded shorter than spelt or wheat. In fact, over-kneading of the dough should absolutely be avoided because it leads to very poor baking results (Fig. 2). The doughs were optimized for each sample in that the water absorption and kneading time were adapted to the kneading curve so that all doughs were optimally kneaded.

Final recipe (percentages based on flour; Fig. 3)
- flour + water = 75g; amount of water was corrected based on flour water absorption
- 1.5% salt
- 1% sugar
- 1% sunflower oil
- 3% yeast
- 0.005% ascorbic acid

The dough was set at 24°C and then left to rest in the proving cabinet for 20 minutes at 32°C and 80% humidity. Bread rolls were made by hand, placed in the proofing cabinet again for 35 minutes (32°C, 80% humidity), and then baked for 22 minutes at 230°C top and 220°C bottom heat. The baking result was evaluated one hour after baking. All samples were then examined using milling and baking test.

The results were finally analyzed using mixed linear models in a one-way ANOVA. For this purpose, the statistical program R (R Core Team 2018) was used with the aid of the package ASREML (Gilmour et al. 2009).

Results & Discussion

In this project, a total of over 70 traits were recorded on 143 emmer varieties and few comparative varieties of common wheat, spelt, durum and einkorn at up to four different locations. It should be emphasized that we recorded most important traits relevant for all stakeholders along the entire supply chain, i.e. research "from farm to fork". Thus, agronomic traits such as yield and low susceptibility against lodging and yellow rust are important for farmers, traits such as kernel yield and flour yield for millers, and water absorption, dough stability and loaf volume for bakers and consumers.

<u>Agronomic properties of emmer</u>

Emmer had on average a significantly lower raw yield compared to wheat and spelt (Fig. 4), with higher plant height, higher lodging and higher susceptibility to yellow rust (data not shown). Our findings confirm the results of previously published literature (Longin et al. 2016). However, a wide range of variation was found for almost all investigated traits between the 143 emmer varieties (Fig. 4). For instance, raw yield ranged from 34 dt/ha to >80 dt/ha. Consequently, it is evident that even in old species, there are varieties with very different trait characteristics in gene banks that need to be (re)elaborated. Furthermore, selection and breeding can help much even in alternative

species, with relatively little effort to improve competitiveness of the new crop species. This can be seen by comparing important emmer varieties of the last two decades (Fig. 5). The first widespread emmer varieties on the market were Ramses and Osiris, as well as Mv Heyges in Hungary and Farvento in Austria. These were followed by newly bred varieties Heuholzer Kolben and slightly later Späth's Albjuwel and Roter Heidfelder. Whereas Ramses, Osiris, Farvento and Mv Heyges were at about 55 dt/ha of raw yield and in some cases very susceptible to lodging in our trials, yields and resistance against lodging was successively improved in the newly bred varieties. The breeding of Späth's Albjuwel and the Roter Heidfelder reached a new level of lodging resistance and leaf health and is already agronomically comparable to the popular spelt landrace Oberkulmer Rotkorn. The latest varieties are continuing this encouraging trend and are now providingaround 80 dt/ha of raw yield with a further reduction in lodging susceptibility, comparable to the popular spelt variety Zollernspelz under extensive farming practices. This underpins a significant breeding progress in the still young emmer breeding, which reduces cultivation risks and necessary raw material prices for more profitable cultivation.

Key traits for millers

First, a standard milling procedure for emmer was developed at DIGeFa. The aim was to achieve the highest possible flour yield comparable to spelt flour of type 630. Extensive analyses on preliminary samples with the Buhler automatic milling machine and the Brabender Quadrumat Junior mill showed that acceptable flour yields in the targeted ash content could be achieved with a wetting of 16% and the use of the Buhler automatic milling machine, while at the same time the starch damage was similar to that of common wheat. This milling was then used as the standard for all samples.

We will focus our illustrations for millers on kernel and flour yields. Emmer is a hulled wheat, which means that the kernels are only obtained by a further working step in the mill. Kernel yield was determined here as the percent by weight of kernels compared to the raw weight after dehulling and cleaning. Spelt and emmer have on average a kernel yield ≥20% lower than common wheat and durum (Fig. 4), einkorn even lower. However, for kernel yield a wide range between 46% and 85% was foundamong emmer varieties, confirming results from spelt (Longin et al. 2016).

Similarly, flour yield to extract refinded flour showed a wide range from 58% to 76% among emmer varieties, slightly below common wheat and spelt reference varieties (Fig. 4). In any case, the differences among the 143 emmer varieties show that it is worthwhile for the millers to select emmer varieties with better kernel and flour yield. Both characteristics do not correlate with each other (Fig. 6), thus both key traits can be maximized in parallel. The currently most important emmer varieties Späth's Albjuwel and Roter Heidfelder are in the medium to good range of the tested emmer varieties. As a concluding remark for the millers: compared to common wheat, emmer has a harder grain and a lower flour yield, but the kernel yield is similar to spelt.

Important traits for bakers

Thanks to the newly developed DIGeFa baking test, we were able to discover a large variance in the breads made from different emmer varieties. For instance, the loaf volume varied between 353 and 510 ml/100g and the height/width ratio between 0.38 and 0.70 (Fig. 4, Fig. 7). As in common wheat, the loaf volume and height/width ratios correlate only moderately (r = 0.49). In our opinion, both traits should be considered in parallel, as shown in Fig. 7 or in a standardized index (baking quality index, Fig. 6), since neither of the two traits alone has sufficient significance. For example, a high loaf volume says nothing about the shape - a flatbread can also have a large volume. The desired round bread shape is better reflected by the height/width ratio of the bread, but without specifying the volume.

Surprisingly, there were Emmer varieties that had a higher loaf volume or height/width ratio than the E wheat variety Genius and the A wheat variety Julius (Fig. 7). The spelt cultivars Franckenkorn and Zollernspelz also had better loaf volume than the common wheat cultivars with similar height/width ratios, which clearly contradicts knowledge from other studies and practice. In contrast, sedimentation values for common wheat were on average three times higher than for emmer (Fig. 4). The moderate baking results of the common wheat varieties can be explained by the recipe adjustment in our baking trial compared to the Rapid Mix test or everyday bakery practice. The emmer baking test was characterized by very careful and short kneading, the use of less yeast and prolonged dough proving, and a higher use of ascorbic acid. This especially suits doughs with low kneading stability and instable doughs. This also shows how varietal assessment based on a single baking trial is sensitive and thus requires a detailed investigation of other quality-related traits.

Based on the dough properties from the mixolab or extensograph, one can clearly see the higher processing tolerance of the common wheat varieties Genius and Julius coupled with higher expected baking volume with more intensive and longer kneading (Fig. 4). In the mixolab, torque measurements at time CS and C2 provide important information on dough stability and kneading tolerance (CS), and tolerance to mechanical stress and heat (C2), respectively. The higher these values, the better for processing and here the common wheat varieties Genius and Julius are clearly better than the tested emmer varieties (Fig. 4). In the extensograph, the energy value says a lot about the expectedbaking volume, the higher the better. The ratio of elongation resistance and extensibility should be in the medium range. Low ratio numbers tend to represent flowing doughs, while high ratio numbers tend to represent short, sticky doughs. The largest number of emmer varieties tended to have a small energy value coupled with small ratio number (Fig. 4), which tended to represent smaller baking volumes and instable doughs. On the other hand, the common wheat varieties Julius and Genius were by far in the positive range, i.e. with high energy value and medium ratio number.

In summary, the newly developed baking test helps to test the baking quality of emmer varieties on the basis of loaf volume and height/width ratio. However, this baking test is not suitable for comparing emmer varieties with common wheat varieties in terms of baking quality. The baking test and the indirect laboratory tests clearly show that emmer varieties differ significantly in terms of processing quality. However, even the best emmer variety in terms of baking quality has different processing properties than common wheat or spelt. Thus, the baker must adapt recipes and baking practice to emmer and not expect that emmer breeding will/can change it to a common wheat quality.

The water absorption of flour has two positive properties at once. On the one hand, baked goods with higher water absorption keep fresh longer, and on the other hand, water is a favorable ingredient in the recipe. Spelt, for example, has a lower water absorption than common wheat and therefore tends to give dry baked products, which a good baker then knows how to correct in the recipe. We could also see this in our data, the water absorption of the spelt reference varieties was significantly lower than that of the common wheat reference varieties (Fig. 4). The water absorption of the emmer varieties varied in a wide range from 56 - 71 ml/100g, but it was on average significantly higher than for common wheat or spelt. Simplified explained, the water absorption of flour is determined by two factors: the more protein or the higher the starch damage/grain hardness, the more water the dough absorbs. Both factors are present in emmer, which is also shown by data from our trials, at least for the correlation of protein content and water absorption (Fig. 6). Unfortunately, we were not able to measure grain hardness and starch damage in the course of the project.

We also measured retrogradation, i.e. bread aging, in the mixolab. The value of the torque at time C5 reflects this; the smaller, the lower the retrogradation, that is the longer the bread keeps fresh (Fig. 4). Here, too, the emmer varieties were on average considerably better than common wheat or spelt. This is noteworthy in that the starch quality for emmer did not look as good as common wheat based on the mixolab data, it showed more of a low viscosity for emmer. Thus, the baker should take care that the dough does not release the much water it binds during rising, e.g. by using oil in the recipe. Conclusion for the baker: Compared to wheat, emmer has more protein, but lower dough stability, lower dough extensibility, higher water absorption and lower retrogradation.

<u>Rapid method for determining processing quality in emmer?</u>

In our opinion, emmer varieties with good processing quality are characterized by the following key traits: high loaf volume and high height/width ratio. On the one hand, we have shown this graphically in Fig. 7, and on the other hand, we have standardized both traits and then summed them up with equal weighting in a baking quality index (Fig. 6). In addition, emmer varieties should have a kneading tolerance as high as

possible. Dough and baking tests are very costly and also require a large quantity of grains, which cannot be measured along the supply chain, neither in breeding, in the trade of grains, nor by the baker. In this respect, the question arises whether these traits can be estimated with high correlation on the basis of the simplest laboratory tests. In common wheat, the protein content and the sedimentation value are used for this purpose in breeding. While in trading, unfortunately, only the protein content is still used, although this only moderately predicts the baking quality. The protein content in our emmer trial correlated and with loaf volume ($r = 0.5$) and height/width ratio ($r = -0.007$), respectively, and thus also only slightly with baking quality index ($r = 0.25$, Fig. 6). In contrast, a high correlation ($r = 0.79$) between sedimentation value and baking quality index was observed. Moreover, the sedimentation value correlated with $r > 0.8$ with the energy value of the extensograph and the dough stability (mixolab: torque at time CS). Therefore, we propose sedimentation value as the method of choice in breeding to test for baking quality in the medium term, which confirms results from common wheat and spelt. Even if methods like sedimentation value, mixolab or extensograph may seem too slow for the trade of emmer, protein content should not be used. Protein content says nothing about baking quality in emmer. An auxiliary characteristic would be the variety name, where major differences can already be determined (Fig. 7), or a mixolab or extensograph measurement.

Tips for the baker's practice

For baking practice, some important findings can be derived from our data. Initial practical experience has confirmed that emmer cannot be processed in the same way as spelt or common wheat. If one wants to produce bread or bread rolls with a lot of emmer, the recipe and dough management should definitely be adapted. The even lower kneading tolerance of emmer compared to spelt absolutely requires a strong reduction of the kneading energy added to the dough, preferring only mixing and little kneading. Also because of the high water absorption, the doughs are even more fluid than those of spelt, so stabilizing intervention is required, e.g. by folding the dough several times or even by using bread baking molds. Also, the emmer doughs do not seem to be able to hold the large amount of water that is absorbed at the beginning.

In bakery practice, the addition of buttermilk or oil has proved positive in this respect. In addition, a long dough proofing process, a reduction in the amount of yeast or the use of sourdoughs considerably improve the baking quality. If this is applied, it is possible to obtain premium baked goods with great taste and long freshness. Nevertheless, it is advisable to present these products separately in the trays and rather invent new pastry variants from emmer than necessarily make an Emmer pretzel, which will always look "different" from a common wheat pretzel. Bread types such as ciabatta, root breads, or whole wheat breads in baking box are ideal. Alternatively, emmer is of course very suitable for waffles and cookies owing to its low dough viscosity.

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Fig.1: Different emmer varieties in field trial Stuttgart-Hohenheim 2020

Fig. 2: Problems in dough production with emmer varieties in the Rapid Mix test (RMT).

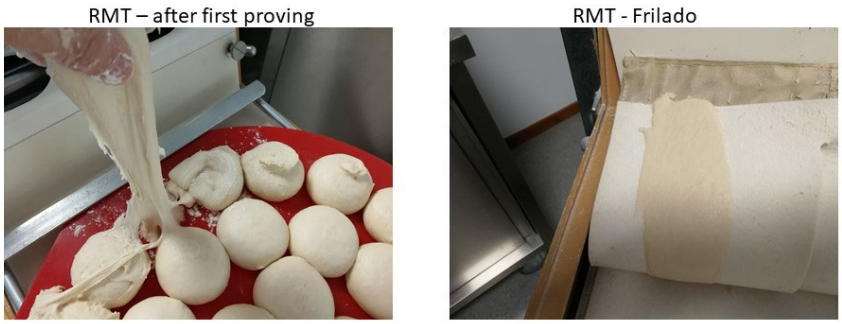

Fig. 3: Comparison of four emmer varieties in the optimized baking trial.

Fig. 4: Important traits for farmers, millers and bakers in percent to the mean value of the common wheat varieties Genius and Julius. For durum (Sambadur, Wintergold) and spelt (Franckenkorn, Zollernspelz), mean values of two varieties are given; einkorn was only the Terzino variety. Emmer - min or - max is the respective minimum or maximum value of all emmer varieties, Emmer - mean represents mean value of all emmer varieties. SDS = sedimentation value; mixolab measurement of torque at time CS = dough stability/knead tolerance; mixolab measurement of torque at time C2 = dough tolerance to mechanical stress and heat; mixolab measurement of torque at time C5 = retrogradation; energy and ratio number from the extensograph after 90 minutes.

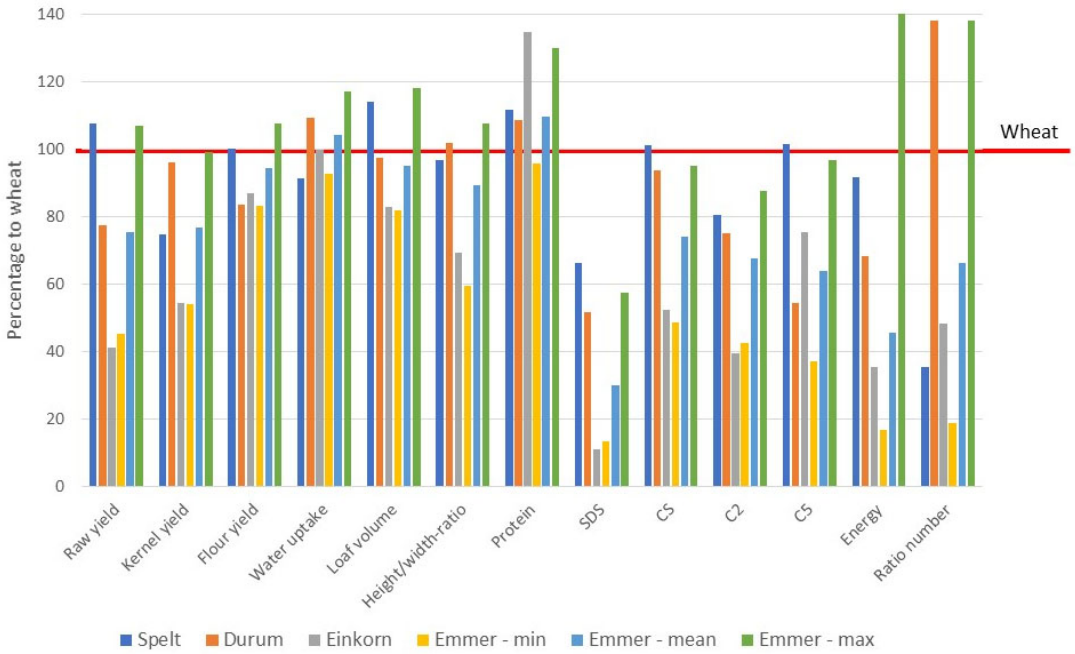

Fig. 5: Breeding progress in emmer shown by the traits yield (dt/ha – higher is better) and lodging (% - lower is better) in a few registered emmer varieties, the best new varieties and the reference spelt variety Zollernspelz.

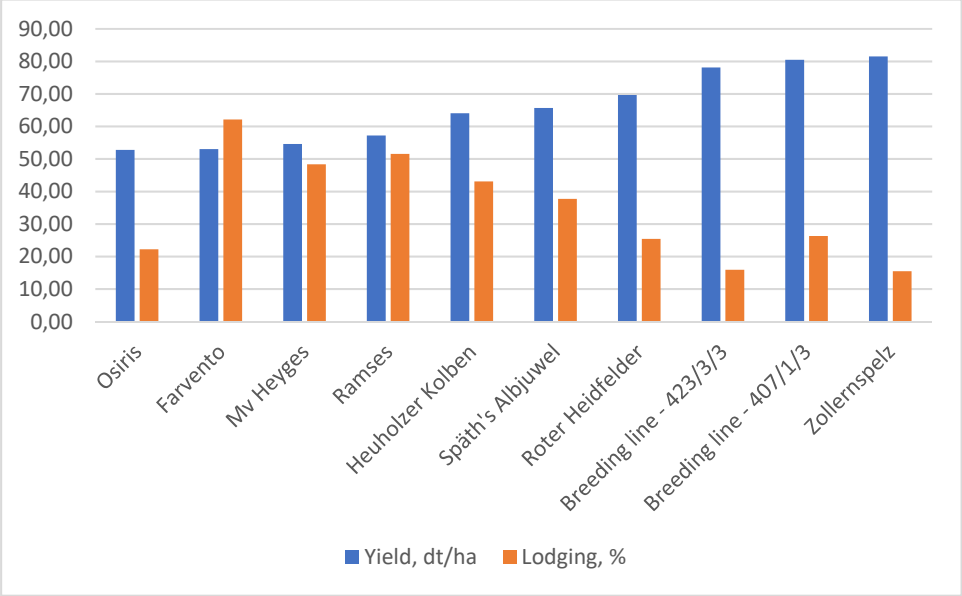

Fig. 6: Pearson's correlation coefficient between the measured traits , (described in detail in Fig.4).

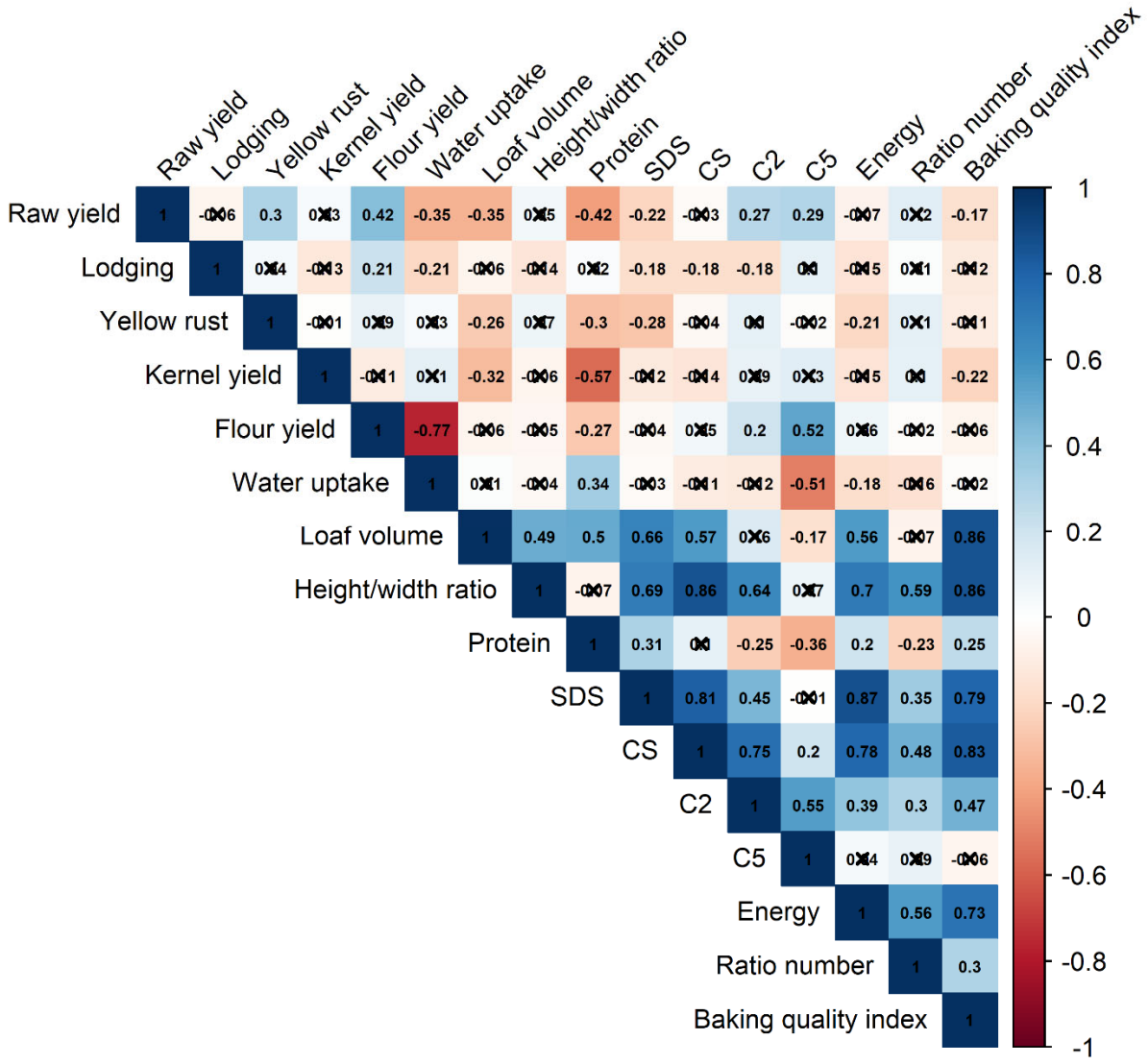

Fig. 7: Mean values from the baking trial for loaf volume and height/width ratio of the test breads averaged over four locations. Known varieties are mentioned by name and the varieties from species other than emmer are highlighted in red.