Agronomy and processing quality of 148 einkorn varieties compared to wheat

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Summary

Consumers are increasinglyinterested in products made with ancient grains. We therefore investigated 148 varieties of einkorn and two leading varieties from common wheat as reference for comparison. A central project outcome was the development of a standard milling and baking trial for einkorn. We determined a large variation across the different einkorn varieties for agronomic and quality traits. For instance, raw yield varied between the einkorn varieties from 38-61 dt/ha. Compared to common wheat, einkorn has on average a lower yield, higher protein content, lower sedimentation volume, lower dough stability, lower extensibility and similar water absorption. These different dough properties of einkorn must be considered for baking trials for einkorn 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. However, good bakery products can be made with the existing quality attributes of einkorn doughs as long as bakers adjust their recipes towards lower kneading energy using additional longer dough rest and/or sourdough. Future establishment of einkorn mainly depends on plant breeding to deliver varieties with higher yield and lower risk of lodging.

Einkorn – cereal with long tradition

Einkorn (*Triticum monococcum* ssp. *monococcum*) is one of the oldest cereals. Like emmer or spelt, it belongs botanically to the large wheat family and originally comes from the Fertile Crescent, the region between the Euphrates and Tigris rivers in present-day Syria and Iran. Einkorn was already part of the human diet when we were still hunters and gatherers, for example, the glacier mummy Ötzi had einkorn with him as provisions. However, einkorn gradually lost its importance and is now only cultivated on very few hectares worldwide. Notably, the einkorn varieties still available today from gene banks are no more than 100 years old, even rather considerably younger.

Like spelt, einkorn is a hulled wheat, which means that the grain is firmly enclosed in the hull and remains in it when harvested. The combination of grain and hull is called spikelet. An additional working step in the mill is required to separate the kernels from the hulls. Currently, einkorn is only grown on a small scale, but the demand for traditional products and raw material alternatives to wheat is increasing, almost faster in the hobby baking sector than among professionals. In initial field studies, we found that einkorn can be grown well in our latitudes but with lower yields than wheat (Longin et al. 2016). This study also showed that einkorn has a higher protein and gluten content but a different gluten composition than wheat (Geisslitz et al. 2019). In addition, bakers report that products made with einkorn only succeed when recipe adjustments are made compared to wheat or spelt.

These studies are all based on a small number of einkorn varieties, although there are several hundred of them stored in gene banks around the world. That is why, together with Strube Research GmbH & Co. KG and the Detmold Institute for Grain and Fat Analysis (DIGeFa), we launched a research project unique for einkorn. We collected several hundred einkorn 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 einkorn varieties from the market to test a total of 148 einkorn varieties across multiple locations and several years in the field and quality laboratory. The aims of these extensive trials were to (1) assess the variability of einkorn varieties in agronomic characteristics as well as important quality traits, (2) develop suitable milling and baking trials for einkorn, (3) investigate possible rapid methods for quality determination in einkorn, and (4) develop practical recommendations for processing einkorn into premium products.

Material and Methods

We cultivated 148 unique einkorn varieties together with two German wheat varieties (Genius and Julius) in a partially replicated trial at a total of five diverse growing locations in yield plots in 2019, 2020, and 2021 (Fig. 1). The conventionally farmed locations were: Stuttgart-Hohenheim (HOH) in 2020, 2021, and Strube in 2019 (2 locations) and 2020. In these trials, heading (EC stage), plant height (cm), and susceptibility to lodging (score 1 = lowest, 9 = highest) were recorded in addition to raw yield (dt/ha). The harvested samples of these plots were used for quality analysis.

All samples from the Strube 1 - 2019, Strube 2 - 2019, and HOH 21 locations were then subjected to intensive quality analysis. These harvested samples were first dehulled, cleaned, and protein content (NIRS, ICC Standard Method 159), hectoliter weight (kg,hl), kernel yield (weight after dehulling and cleaning in % to raw yield), and thousand kernel mass (TKG, g) were recorded. In addition, sedimentation value (with sodium dodecyl sulfate; ICC Standard Method 151) and falling number (ICC Standard Method 107/1) were determined. DIGeFa first developed a standard milling test for einkorn wholegrain flour. Extensive analyses on preliminary samples with the Buhler automatic milling machine showed that acceptable starch damage similar to that of wheat can be obtained with a wetting of 16% and the use of the Buhler automatic milling machine. To meet the requirement of a wholegrain flour, the bran fractions from the Buhler automatic milling machine were re-milled on the Retsch mill before being blended with the passage flour to produce the final wholegrain flour. This milling was then used as the standard for all samples. Using these flours, various dough properties were then investigated with the aid of the mixolab (ICC Standard Method 173) and the extensograph (ICC Standard Method 114/1).

In addition, a standard baking test for einkorn was developed on preliminary samples of several einkorn varieties. It was evident from the mixolab kneading curves that einkorn should be kneaded for a shorter time than spelt or wheat. Over-kneading of the dough should absolutely be avoided for einkorn, because this leads to very poor baking results (Fig. 2). The water absorption from the rheological tests was used as the basis for the water dosage during dough production for the baking tests. The kneading time of each dough was determined individually on the basis of the kneading curve. After reaching the kneading maximum, the kneading was stopped.

The following was used as the final recipe (percentages based on flour):

- Flour + water = 75g; amount of water was corrected based on flour water absorption.
- 1.5% salt
- 1% sugar
- 1% sunflower oil
- 2% yeast
- 0.01% ascorbic acid

The dough was set at 24°C and then left to rest in the proofer for 20 minutes at 32°C and 80% humidity. It was then used to make rolls by hand, placed in the proofer again for 50 minutes (32°C, 80% humidity), and then baked for 22 minutes at 230°C top heat and 220°C bottom heat. The evaluation of the baking result was done one hour after baking. The established test differs from baking tests with wheat primarily in the use of wholegrain flour, significantly reduced kneading energy, hand leavening, and the use of less yeast and longer proofing. All samples were then tested using this milling and baking trial.

In another field trial, frost hardiness and vernalization requirement were tested at three locations. In the frost test, it is important that really heavy frost prevails and snow cover is avoided, which we realized by means of Weihenstephan box test. In this system, frost damage is assessed after the winter on the basis of dead leaves (1 = no frost damage, 9 = high frost damage). In the vernalization test, it is important to exclude any cold stimulus. This was ensured by sowing at the end of April. In summer, it was then assessed to what extent these varieties had formed ears (1 = no need for vernalization = all ears present; 9 = high need for vernalization = no ears present).

The results were finally analyzed implementing mixed linear models. 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 about100 traits were recorded on 148 einkorn varieties and two comparative wheat varieties at up to five different locations. It should be emphasized that we recorded most important traits for all stakeholders along the entire supply chain, i.e. research "from farm to fork". Thus, agronomic traits such as yield, stability and winter hardiness are important for farmers, traits such as grain size and kernel yield for millers, and water absorption, dough stability and pastry volume for bakers and consumers.

Agronomic properties of einkorn

It is known from previous trials that einkorn has very long straw and thus tends to lodging during heavy rainfall or storms. Therefore, the trial was run with one third of the nitrogen fertilization rate of wheat and a single application of growth regulators. This represents extensive conventional cultivation, which is currently a common practice for einkorn.

Under these conditions, einkorn had on average a significantly lower raw yield compared to wheat, with higher plant height and lodging and significantly later flowering (Table 1 and Fig. 3). The later flowering is due to a very delayed plant development in spring, thus einkorn cultivation requires good weed management. This confirms the findings of other studies from the literature (Longin et al. 2016). Frost hardiness in einkorn, on the other hand, was significantly better than in the tested frost-hardy winter wheat varieties Julius and Genius. Interestingly, better frost hardiness in many einkorn varieties was not linked to vernalization requirement, as has been the case in all winter cereals. In fact, the correlation of both traits was slightly negative i.e. -0.48 (Fig. 5). Thus, we were able to identify numerous very frost-hardy einkorn varieties that had no vernalization requirement at all. The farmers could thus sow the same variety before or after winter, which is a great advantage when crop rotations become more complex. A study of the genetics underlying these traits in einkorn indicated that the few gene loci for vernalization and frost hardiness, which were known and very important in common wheat, did not play a role in einkorn. Thus, these unique properties in einkorn seem to be genetically independent from the frost and vernalization genes known from common wheat. In summary, we found a large variation among cultivars for all measured traits.

These findings indicate several things. First, even in old species, there are varieties with very different trait characteristics in gene banks that need to be (re)elaborated. Second, selection and breeding can help to a greater extent even in alternative species with relatively little effort to improve yield and reduce cropping risk, and thus sustainably increase the competitiveness of the new crop species. And third, the establishment of an (old) species is not a no-brainer, but requires precise knowledge on key traits along the supply chain, which confirm results from spelt (Longin and Rapp 2017) and emmer (Afzal et al. 2021). In einkorn, for example, variety selection can increase yields by >30% and reduce cropping risk (especially lodging) by >100%. The einkorn varieties Monomax and LDPhi, which are important in cultivation, are clearly better in these traits than most of the tested einkorn varieties. To warrant future einkorn cultivation, breeding is required for less lodging, faster plant development in the early growth stages and significantly higher yield.

Important properties for milling

Here we have focused on kernel yield and kernel size. Einkorn is a hulled wheat, which means that the kernels remain tightly enclosed by the hulls during harvesting and are not obtained until a further processing step. Kernel yield was determined as the percentage by weight of kernels after dehulling and cleaning compared to the raw yield. Kernel yield varied among einkorn varieties from 59-73% (Fig. 3), which is lower than in spelt and emmer (Longin et al. 2016, Afzal et al. 2021).

Einkorn also has a significantly smaller TKM than wheat (Table 1, Fig. 3), averaging only 60% of wheat, and even the largest einkorn grains are still significantly smaller than wheat grains. In this respect, it makes economically no sense to produce refined flour from einkorn, which would lack the beneficial ingredients of einkorn (Ziegler et al. 2016). It has been recognized from practical experiences of milling that einkorn has the property to clog the sieves in the mills with fine, slightly sticky particles. Thus, the milling of einkorn requires more attention from the miller.

In summary, the differences between the 148 einkorn varieties show that it is considerably worthwhile for the millers to select einkorn varieties with better kernel yield and grain size. The einkorn varieties Monomax and LDPhi, which are important in cultivation, are slightly above average in the comparison of all tested einkorn varieties.

Dough and baking properties of einkorn

The water absorption by flour has two important positive properties. On the one hand, pastries with higher water absorption keep fresh longer, and on the other hand, water is a cheap ingredient in the recipe. The water absorption of einkorn varieties varied only slightly from 60-66ml/100g, and was on average slightly lower than that of wheat. The water absorption in the flour is simplistically determined by two factors: the more protein or the higher the starch damage/grain hardness, the more water the dough absorbs. Einkorn has a higher protein content than wheat and this was also positively correlated with water absorption (Fig. 5). Why water absorption was nevertheless lower in einkorn than in wheat warrants further research; we had not measured grain hardness and starch damage.

Thanks to the newly developed baking test by DIGeFa, we were able to determine a large variance between the einkorn varieties in baking quality. For example, the loaf volume varied between 260 and 314 ml/100g and the height/width ratio between 0.36-0.59 (Table 1, Fig. 4). As in wheat and emmer, the loaf volume and height/width ratios do not correlate well with a correlation coefficient close to zero in einkorn. In our opinion, both ratios should be considered in parallel, graphically as in Fig. 4 or in a standardized index (baking quality index, Fig. 5), since neither trait 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 oval bread shape is better reflected by the height/width ratio of the bread, but without specifying the volume.

While few einkorn varieties had a similar height/width ratio as the E wheat variety Genius and the A wheat variety Julius, all einkorn varieties had a significantly lower loaf volume. It should be noted that the baking quality of the wheat varieties is probably underestimated. The einkorn baking trial was characterized by very careful and short kneading, the use of less yeast and prolonged dough rest, and a higher use of ascorbic acid. This is especially beneficial for doughs with low kneading stability and instable doughs.

Based on the dough properties from the mixolab or extensograph, one can clearly see the higher processing tolerance of the wheat varieties Genius and Julius coupled with higher expected baking volume with more intensive and longer kneading. In the mixolab, the torque measurements at time CS and C2 (Nm) 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 wheat varieties Genius and Julius are considerably better than the tested einkorn varieties (Tab. 1, Fig. 3).

The large number of einkorn varieties tended to have small energy value coupled with small ratio number in the extensograph, which led to the expected smaller baking volumes and instable “running” doughs based on knowledge from wheat, spelt, and emmer datasets (Longin and Rapp 2017, Afzal et al. 2022). In contrast, the wheat varieties Julius and Genius were in the positive range by a significant margin, i.e., high energy value and medium ratio number. However, few einkorn varieties with very good properties could be found for all dough and baking properties. Nonetheless, these are poor in both yield and lodging. In summary, the newly developed baking test helps to test einkorn varieties among themselves in their baking quality on the basis of loaf volume and height/width ratio. However, this baking test is not suitable for comparing einkorn varieties with wheat varieties in baking quality.

In order to select or breed einkorn varieties with better baking properties, two things are important in our opinion. On the one hand, they should perform well in the newly developed baking test, preferably with a high loaf volume and a high height/width ratio. On the other hand, however, in the medium to long term, they should be bred for an improvement in kneading tolerance and energy values measured in the extensograph. Dough and baking trials are very costly and also require a large quantity of kernels, which are not available in the breeding process until late generations. This raises the question of the extent to which these properties can be estimated with high correlation on the basis of simpler laboratory tests. In wheat, one takes the protein content and the sedimentation value for this purpose. The protein content correlated with $r = 0.35$ and $r = -0.16$ with the loaf volume and the height/width ratio, respectively (Fig. 5). Sedimentation value correlated with $r = -0.04$ and $r = 0.63$ with loaf volume and height/width ratio, respectively. The sedimentation value also correlated with $r > 0.85$ with the extensograph energy value and dough stability (mixolab: torque at time CS). In this respect, we recommend sedimentation value and extensograph as the method of choice to test baking quality in the medium term in einkorn breeding, which confirms results from wheat, spelt, and emmer (Longin and Rapp 2017, Afzal et al. 2022). Although methods such as sedimentation value, mixolab, or extensograph may seem too slow for trading einkorn in the supply chain, protein content should not be relied upon. Protein content says nothing about baking quality in einkorn. An auxiliary trait might be the variety name, here larger differences can be determined (Tab. 1).

Premium baked goods with einkorn require adapted recipes and good bakers

Important findings can be derived from this project for practical baking. We confirm the initial practical experiences that recipes must be adapted if bread or bread rolls with a high proportion of einkorn are to be produced. The even lower kneading tolerance as with spelt absolutely requires a strong reduction of the kneading energy added to the dough, rather only mixing. The doughs are even more fluid and sticky than spelt, so stabilizing methods are required, e.g. by folding the dough several times or by using bread baking molds. In addition, long dough leavening, reduction of the amount of yeast, use of pre-doughs or sourdoughs considerably increase the baking quality. If the recommended modifications are applied, it is possible to obtain beautiful baked goods with great taste and long freshness. Nevertheless, it is advisable to present these products in special places in the trays and rather invent new pastry products than necessarily make an einkorn pretzel that will always look "different" from a wheat pretzel. Bread types such as rustic roots or classic whole-grain breads in a box shape are suitable. Alternatively, einkorn is very suitable for waffles, cookies, fruit slices and other sweet pastries because of its yellow color and attractive nutty flavor.

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Fig. 1: Different Einkorn varieties in the field trial in Stuttgart-Hohenheim 2021

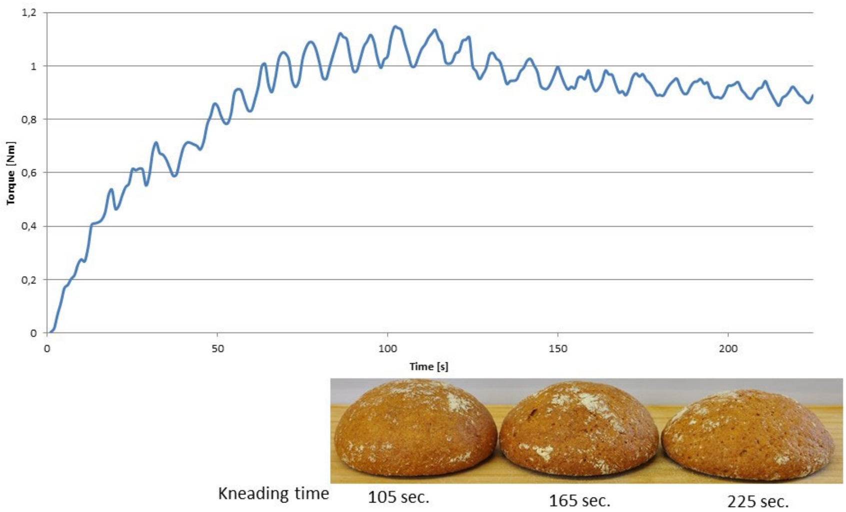

Fig. 2: Baking tests with one einkorn variety kneaded for different times in the Mixolab (see kneading curve above).

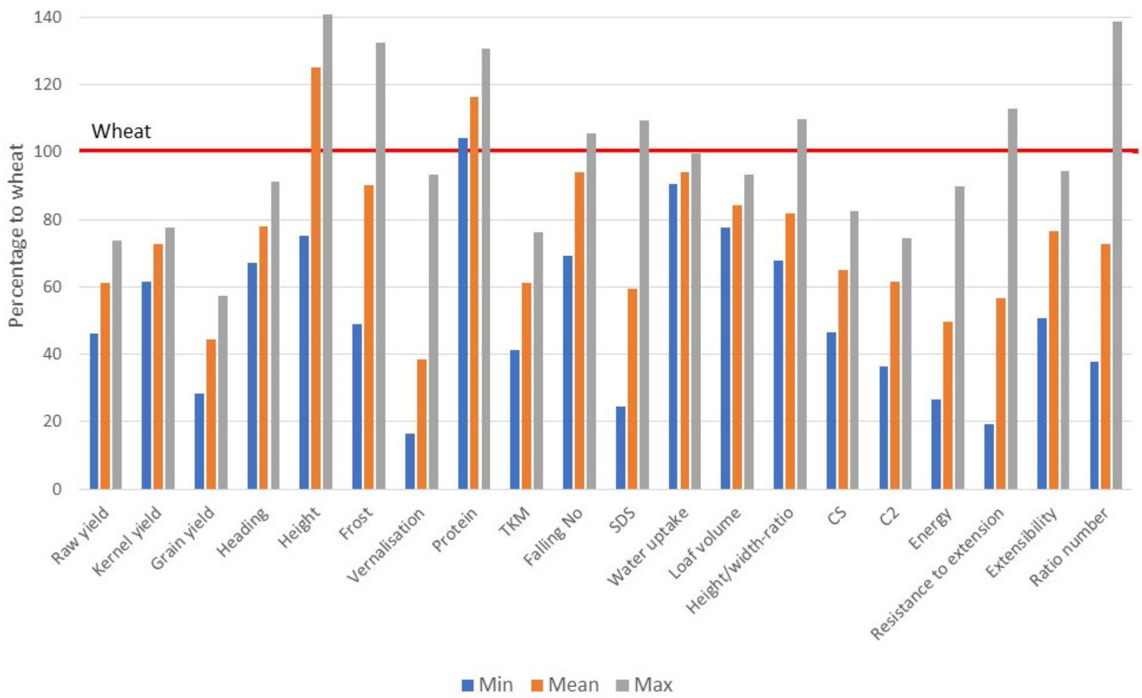

Fig. 3: Range of variation (Min, Mean, Max = minimum, mean and maximum trait values) of the 148 einkorn varieties averaged across several locations compared to the mean of two wheat varieties (Frost = damage by frost; vernalization = requirement for vernalization; TKM = thousand grain mass, SDS = sedimentation value, CS and C2 = torque in Nm of mixolab at the respective time; extensograph results shown for 45 min proofing time).

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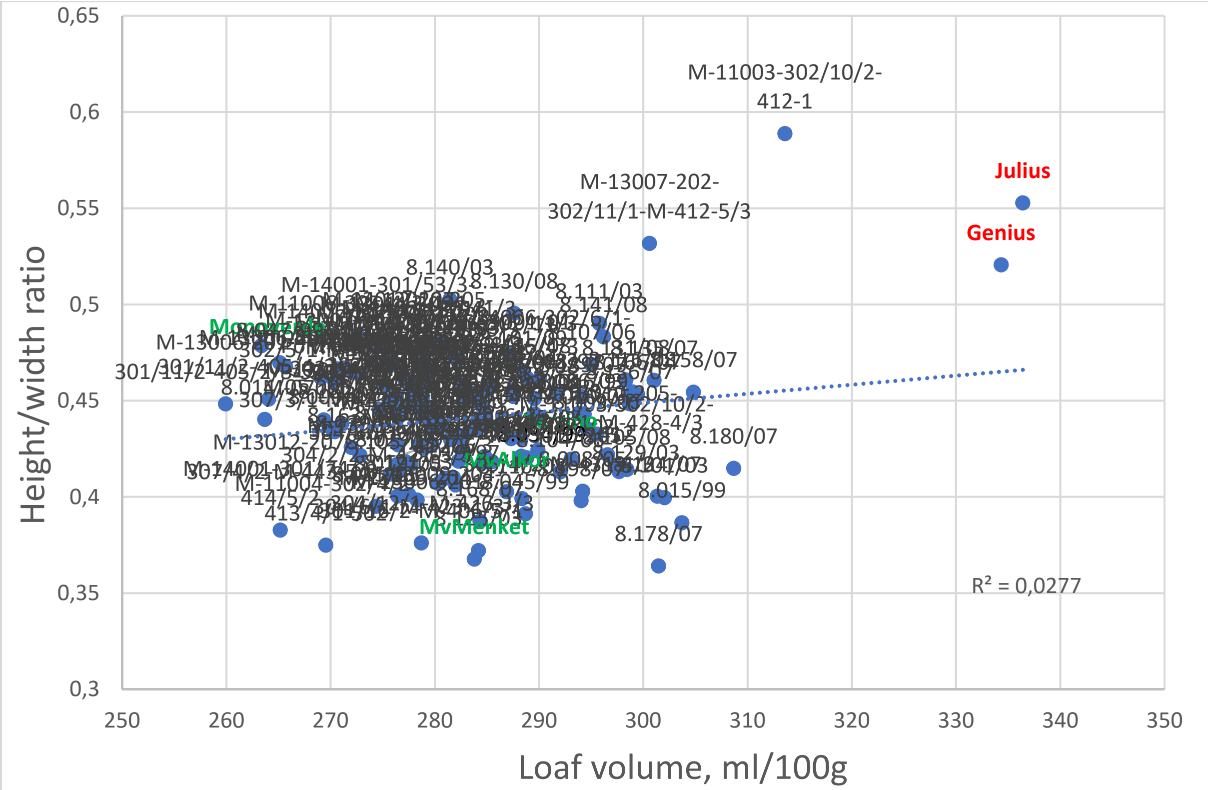

Fig. 4: Mean value from the baking trial for the loaf volume and the height/width ratio of the test breads averaged over three locations. Important einkorn varieties are marked in green, the two wheat varieties in red.

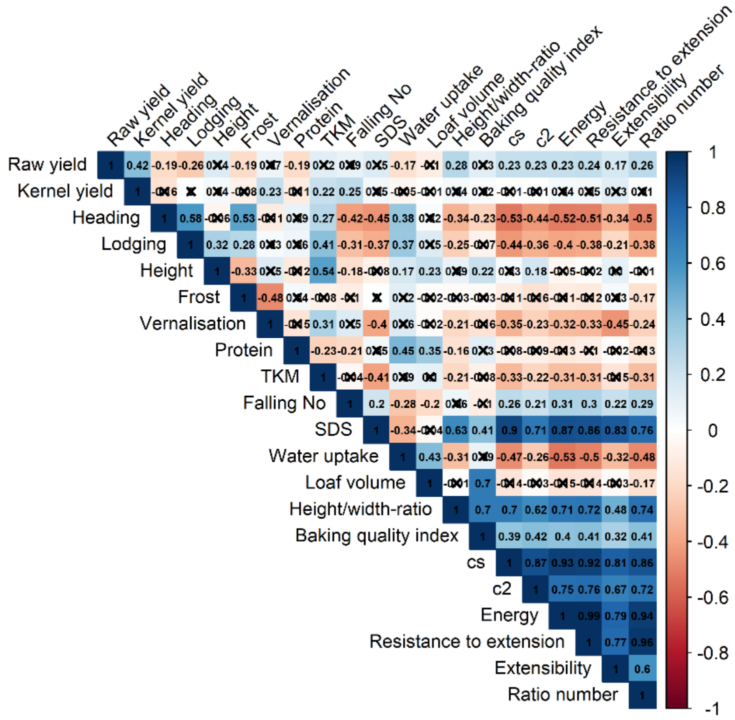

Fig. 5: Pearson's correlation coefficient between important traits from agronomy and processing (Coefficients not crossed out are significant at the probability level of $p < 0.05$; Frost = damage by frost; vernalization = requirement for vernalization; TKM = thousand grain mass, SDS = sedimentation value, CS and C2 = torque in Nm of mixolab at the respective time; extensograph results shown for 45 min proofing time).

Table 1: Variance components and variety means from series analyses across all available growing locations for selected traits (Min, Mean, Max = minimum, mean, and maximum trait values for the 148 einkorn varieties; LSD = least significant difference at the 5% probability level, σ^2_G = genetic variance, σ^2_{GxE} = genotype x environment interaction variance, σ^2_e = residual error variance; h² = heritability; Frost = frost damage, Vernalisation = vernalisation requirement, TKM = thousand grain mass, SDS = sedimentation value, WA = water absorption; CS and C2 = torque of mixolab at respective time; extensograph results shown for 45 min proofing time, *, **, *** significant at 0.05, 0.01 and 0.001 probability levels).

	Lager (1-9)	Ä.schieben EC Stadium	W.höhe cm	Rohertrag dt/ha	Frost (1-9)	Vernali-sation (1-9)	Protein %	TKG g	Fallzahl sec	SDS ml	WA ml/100g	Vol.Ausbeute ml/100g	H/B-Verhältnis	CS Drehmoment in Nm	C2 Drehmoment in Nm	Energie cm²	Dehnwieder-stand (BE)	Dehnbar-kein (mm)	Verhältnis-zahl
Common wheat variety Julius	1.09	71.30	87.42	84.64	5.81	8.99	14.34	43.99	381.76	50.18	65.13	336.42	0.55	1.05	0.56	33.48	202.48	107.16	1.97
Common wheat variety Genius	1.58	71.39	83.02	81.71	7.29	8.84	14.90	38.45	406.14	52.65	66.59	334.34	0.52	1.10	0.58	62.31	317.60	122.55	2.56
Monoverde	1.44	54.22	106.41	47.68	6.17	2.21	16.41	25.48	398.35	27.15	61.85	263.38	0.48	0.72	0.39	24.49	158.18	84.14	1.88
Monomax	2.26	58.85	110.04	59.15	7.90	4.03	15.98	27.15	354.77	44.46	60.92	265.69	0.47	0.82	0.42	31.24	192.70	100.04	1.94
Terzino	1.90	55.87	115.47	52.79	3.49	3.05	17.36	25.57	340.61	17.52	62.43	288.29	0.43	0.66	0.37	19.33	120.03	80.52	1.47
Einkorn: Min	1.44	48.02	64.09	38.28	3.21	1.46	15.25	17.05	273.49	12.62	59.69	259.93	0.36	0.50	0.21	12.79	49.80	58.45	0.85
Einkorn: Mean	3.16	55.61	106.71	50.79	5.92	3.42	17.05	25.27	370.58	30.58	61.99	282.97	0.44	0.70	0.35	23.77	147.42	87.94	1.65
Einkorn: Max	7.05	65.00	120.03	61.46	8.68	8.33	19.13	31.46	416.43	56.25	65.59	313.60	0.59	0.89	0.43	43.06	293.96	108.27	3.15
LSD (5%)	1.83	3.67	8.07	10.28	2.57	1.92	1.34	2.20	36.24	7.62	1.41	20.48	0.04	0.06	0.06	5.58	37.53	11.92	0.42
σ^2_G	1,44***	9,56***	72,54***	12,01***	1,81***	3,42***	0,18***	5,19***	343,62***	93,41***	1,03***	43,08***	0,001***	0,006***	0,001***	27,42***	1616,20***	69,07***	0,11***
σ^2_{GxL}	0,69**	3,97***	12,74***	22,68***	1,35***	1,81***	0,30***	0.06	302,14***	5.37	0,30***	69,09***	0.00	0,001**	0.00	6,20***	211,71**	21,04**	0,020*
σ^2_e	1.37	2.78	28.95	15.54	1.43	0.22	0.33	1.84	181.11	17.24	0.43	90.95	0.00	0.001	0.001	5.46	334.31	33.81	0.05
h²	0.78	0.85	0.90	0.48	0.68	0.87	0.45	0.89	0.68	0.93	0.80	0.45	0.75	0.93	0.75	0.88	0.90	0.79	0.84