Mineralstoffe und deren Verfügbarkeit in Mehlen und Broten verschiedener Weizenarten

Minerals and their availability in flours and breads of different types of wheat

Prof. Dr. Friedrich Longin, Landessaatzuchtanstalt der Universität Hohenheim, Dr. Jens Pfannstiel, Dr. Ute Bertsche, Dr. Tanja Melzer und Andrea Ruf, Core Facility der Universität Hohenheim, Christoph Heger, Backproduktionsberater, Bäckermeister und Brotsommelier, Tobias Pfaff, Schulleiter der Akademie Deutsches Bäckerhandwerk Südwest e.V., Prof. Dr. Markus Rodehutscord, Dr. M. Schollenberger, Institut für Nutztierwissenschaften, Universität Hohenheim

Summary

Wheat is very important for a healthy and sustainable diet for the growing world population, which is partly due to the high mineral content. However, these are at least partially bound in a phytate complex in the grain and are therefore not available to humans. We have therefore undertaken several series of tests, on the one hand to measure the levels of minerals, phytic acid and phytase activity in various types of wheat, spelt, emmer and einkorn, and on the other hand to investigate the potential of different bread dough methods to reduce the phytic acid concentration and thus the availability of minerals to increase. For all components examined, we found a variance both between the varieties within a species and between the wheat species. Wholemeal flours, especially from emmer and einkorn, seem to have even more minerals than wheat, but also a significantly higher concentration of phytic acid with similar phytase activity. Only einkorn had an increased phytase activity compared to the other types, but still significantly lower than that of wholemeal rye flour. The dough process had a significantly greater influence on the phytic acid concentration in the bread than the choice of variety for the production of wholemeal flour. Long yeast or sourdough processes and the use of wholemeal rye flour in mixed wheat bread minimize the concentration of phytic acid in the bread. The different dough processes also have the potential to positively influence other ingredients such as FODMAPs or acrylamide as well as the baking quality and aromas of the bread.

Wheat (Triticum aestivum ssp. aestivum) is one of the most important staple foods worldwide and its daily consumption is part of a healthy and balanced diet according to leading world health organizations such as the WHO, FAO and EFSA. However, whole grain products should be consumed in particular, because the dietary fibers and minerals are highly concentrated in the surface layers and seedlings of the grains (e.g. Gupta et al 2021, Huang et al 2015). According to the WHO, however, more than two billion people worldwide suffer from a lack of micronutrients such as folate, iron (Fe), zinc (Zn) and selenium (Se), the so-called hidden hunger. This is particularly pronounced where not enough fruit, vegetables and animal products are available for a balanced diet in addition to cereals, i.e. in parts of Asia and especially in African countries south of the Sahara. In these countries, for example, the large wheat research centre CIMMYT is also active with a special wheat breeding program in which, in addition to good agronomic performance, breeding is also carried out for higher levels of minerals such as Fe, Zn and Se (Gupta et al. 2021). But even in Europe, it is estimated that up to 20% of the population is undersupplied with minerals (e.g. Rippin et al. 2020).

Phytic acid is the main storage form of phosphate in grain and is not available to humans in the existing form. In addition, minerals such as Fe, Zn, magnesium and Se are partially bound by phytic acid in a complex and therefore cannot be absorbed by us humans (e.g. Zimmermann et al 2002, Brinch-Pedersen et al 2013). Most of these minerals are excreted undigested, which in the case of phosphate is of particular importance for the environment.

Thus, the availability of minerals is a nutritional issue for humans and animals as well as an issue of environmental and resource protection and has long been the subject of scientific research. Ideally, a grain has a lot of minerals, little phytic acid and a high activity of the grain's own phytase (for a review article: Brinch-Pedersen et al 2013). While in animal nutrition the availability of minerals is increased above all by the addition of microbial phytases in animal feed, the recipe and the dough process during baking appear to be of particular importance in human nutrition. For example, it is known that rye has a significantly higher phytase activity than wheat (Brinch-Pedersen et al 2013), while spelt has a similarly high phytase activity as wheat (Zimmermann et al. 2002). In contrast, barley, maize and rice have significantly lower phytase activity (Zimmermann et al 2002, Brinch-Pedersen 2013). Prolonged dough processing, especially when using sourdough, also seems to greatly reduce the phytic acid concentrations in bread (Brinch-Pedersen et al 2013, Fretzdorff and Brümmer 1992, Lopez et al 2001), which also significantly improved the uptake of minerals, at least in rat experiments (Lopez et al 2003). It is also well known from studies with pigs that a reduction in the concentration of phytic acid in the diet leads to an increased intake of minerals.

So far, however, little is known about mineral and phytate contents and phytase activities in alternative wheat species such as spelt (Triticum aestivum ssp. spelta) and in particular emmer (Triticum turgidum ssp. dicoccum) and einkorn (Triticum monococcum), especially since such studies include a representative number of varieties per species should be considered in comparable cultivation environments.

The aforementioned CIMMYT wheat research program to increase mineral intake in developing countries relies not only on increasing mineral content but also on increasing phytase activity in wheat. The extent to which such a difficult undertaking is justified is significantly influenced by whether the differences in phytic acid concentrations and phytase activities between the varieties of a species are large and how large these differences are compared to the reduction possibilities through dough processing in breadmaking. So far, however, this has not been sufficiently investigated in the wheat species mentioned.

Experimental setup

We have therefore carried out several test series in which numerous types of grain such as wheat, spelt, emmer and einkorn were grown at several locations. Their wholemeal flours were then examined in the laboratory and some of the bread baked and also examined.

In **test series 1**, 13 varieties each of wheat, spelt, emmer and einkorn were grown at three different locations and the minerals in their wholemeal flour were determined in mg/kg using ICP-OES after microwave-assisted digestion. In test series 2, eight varieties each of wheat, spelt, emmer and einkorn were grown at three different locations. Representative mixed samples of each variety were then created from the harvest samples from the three locations. The following key figures were recorded on the wholemeal flour of this mixed sample: amount of dietary fiber in g/100g using AOAC 991.43, amount of phytic acid (IP6) in umol/g TS using chromatography according to Zeller et al. (2015) and the phytase activity in mU/g TS using direct incubation according to Greiner and Egli (2003).

From the 8 mixed wheat varieties of this test series, bread was then baked by an experienced master baker using three dough processes and the phytic acid concentration was determined. The following dough methods were used:

1. Direct yeast dough method with 500g wholemeal flour, 450g water, 10g salt and 15g yeast. The doughs were at room temperature for three hours from setting to pushing the finished bread.
2. Long yeast dough process with 500g wholemeal flour, 450g water, 10g salt and 5g yeast. The doughs were prepared the day before, refrigerated at 4°C for 18 hours and then left at room temperature for a further three hours from taking them out of the refrigeration to pushing the finished bread into shape.
3. Sourdough with rye starter according to the Detmold 1-step method with acidification of 25% of the flour, this 25% being a standard wholemeal rye flour with a determined phytase activity of 7800 mU/g TS and phytic acid concentration of 9.5 µmol/g TS. Specifically, 125g wholemeal rye flour, 100g water, 7g starter rye were prepared and allowed to rise at room temperature for 18 hours. Then 225g sourdough, 375g wholemeal wheat flour, 350g water, 10g salt and 10g yeast were kneaded and it took three hours at room temperature until the shaped loaves were baked.

In **test series 3**, three types of spelt were grown at three locations. Representative mixed samples of each variety were then created from the harvest samples from the three locations. The following key figures were recorded on the wholemeal flour of this mixed sample: mineral and phytic acid content, as well as sugar alcohols, mono-, di- and oligosaccharides in mg/100g using anion exchange chromatography with pulsed amperometric detection (sugar alcohols, mono- and disaccharides based on Thermo Fisher Scientific Technical Note 72225; Oligosaccharides according to Thermo Fisher Scientific Application Note 1149) after aqueous extraction (Menge-Hartman et al 2009). In addition, an experienced master baker baked bread from the wholemeal flours in five batches and determined the concentration of minerals and phytic acid as well as sugar alcohols, mono-, di- and oligosaccharides in the bread. In addition, the amount of acrylamide in µg/kg in the crust of the test bread was analyzed according to Rosen and Hellenäs (2002). The following dough processes were carried out:

1. Direct yeast dough process with 500g wholemeal flour, 350g water, 10g salt and 15g yeast. The doughs were at room temperature for three hours from setting to pushing the finished bread.
2. Long yeast dough process with 500g wholemeal flour, 350g water, 10g salt and 5g yeast. The doughs were prepared the day before, refrigerated at 8°C for 18 hours and then left at room temperature for a further three hours after removing them from the refrigeration before final shaping.
3. Detmold 1 stage sourdough with acidification of 15% of the flour quantity. For this purpose, 75 g wholemeal spelt flour, 75 g water, 7.5 g spelt starter were prepared and allowed to rise at room temperature for 18 hours. Then 150g sourdough, 425g wholemeal spelt flour, 275g water, 10g salt and

10g yeast were kneaded and it took three hours at room temperature before the shaped loaves were baked.

4. Monheim salt sourdough at acidification of 15% of the amount of flour. For this purpose, 75 g of wholemeal spelt flour, 75 g of water, 15 g of spelt, 1.5 g of salt were prepared and allowed to rise for 18 hours at a temperature falling from 35°C to 25°C. Then 150g sourdough, 425g wholemeal spelt flour, 275g water, 8.5g salt and 10g yeast were kneaded and it took three hours at room temperature before the shaped loaves were baked.
5. Berliner short sourdough with acidification of 15% of the flour. For this purpose, 75g wholemeal spelt flour, 75g water, 15g spelt starter were prepared and allowed to rise for four hours at 35°C. Then 150g sourdough, 425g wholemeal spelt flour, 275g water, 10g salt and 10g yeast were kneaded and it took three hours at room temperature before the shaped loaves were baked.

The mineral content of flours varies considerably

For all nine minerals measured, we were able to determine large concentration differences both within the species and between the species (Fig. 1). For example, the amount of Zn between the wheat types varied from 17.4 to 27.9 mg/kg with an average of 20.7 mg/kg wholemeal flour in the 12 tested wheat varieties of test series 1. Thus, the variety had the highest Zn content 60% more Zn than the lowest grade. Comparing species means, wheat had the lowest zinc content, while einkorn had the highest zinc content at 35.1 mg/kg wholemeal flour, a difference of 170%. Similar tendencies were observed for the other minerals. Looking at all the minerals together, spelt and especially emmer and einkorn had significantly more minerals in wholemeal flour than wholegrain wheat, which is already considered an important source of minerals in human nutrition.

In addition to these observed differences, components of wheat grains always depend on the growing environment. The 12 tested wheat varieties had an average of 15 mg Zn per kg wholemeal flour at the Hoh cultivation site, while this was almost 25 mg/kg wholemeal flour at the EKW cultivation site (Fig. 4), even though the cultivation practice was the same at all locations. However, soil differences and climatic conditions such as temperature and rainfall lead to very different availability of nutrients for the plants, phenomena that a farmer can only influence to a very limited extent. Conversely, the individual varieties at each site had a similar ranking of mineral content. Thus, by choosing a variety within a species or by choosing a different species (einkorn instead of wheat), the mineral content in the value chain can be increased, even if the absolute values depend on the specific local cultivation conditions.

Availability of minerals: the baker does it

When it comes to the availability of minerals, we take a simplified look at the amount of phytic acid in wholemeal flour of different types and types of wheat and the breads baked from it using different dough processes. In the flours, as for the minerals, we also found within and between species variability in phytic acid concentration (Fig. 2A). While phytic acid concentrations between varieties of a species varied by only about 2 µmol/g TS, the differences between species were larger and statistically significantly different. As with the mineral content, emmer and einkorn in particular had significantly higher concentrations of phytic acid. This means that these species have more minerals, but also more of them bound in the phytic acid complex and therefore only partially available to us humans.

It is already known from the literature that phytic acid is partially broken down in the dough process to make bread and that this depends, among other things, on the activity of the enzyme phytase (e.g. Brinch-Pedersen et al 2013). For this reason, in addition to the phytic acid concentration, we also determined the phytase activity in the flours of test series 2. There was also a variance between the varieties in terms of phytase activity found within a species and across species with roughly similar magnitudes. Only einkorn had a significantly higher, statistically significant phytase activity with an average of 3300 mU/g DM than wheat with an average of 2295 mU/g DM. To what extent this increased phytase activity can compensate for the higher concentration of phytic acid in the einkorn flour has to be shown in further studies. However, all types of wheat have a lower phytase activity than reported for rye (Zimmermann et al 2002, Brinch-Pedersen et al 2013), which was also experimentally proven in this study, at least for the wholemeal rye flour used in test series 2 (7800 mU/g DM).

In order to compare the influence of the choice of variety within a species on the phytic acid concentration with the influence of different dough methods, we undertook two series of experiments with bread baking. First, we baked three different types of spelt in five different dough processes (test series 3). Two yeast dough methods popular among bakers and three popular sourdough methods were used. All dough processes significantly reduced the phytic acid concentration (Fig. 3A). The breakdown of phytic acid was greatest in all three types of spelt in the long yeast dough process, closely followed by the three sourdough processes. The differences between the types of spelt in the concentration of phytic acid in the flour and in the bread were smaller than the difference between the individual dough methods.

In order to examine the influence of the variety more precisely, we then compared eight types of wheat in a further test series, but only in three dough processes. We used the two yeast dough lines from test series 3, but only one sourdough line. It was confirmed that the choice of dough influences the degradation of phytic acid when baking bread significantly more than the choice of a variety with a possibly lower phytic acid concentration or higher phytase activity (Fig. 3B). We were able to show again that the long yeast dough breaks down phytic acid very well, which has not been described in the literature before. Finally, we designed an optimized sourdough process compared to the spelt study. The Detmold 1-stage sourdough method was used again, but instead of 15% of the flour, 25% of the flour was acidified and the flour in the sourdough was not the type-specific wheat flour, but standard wholemeal rye flour. The idea behind it was that rye, due to its significantly higher phytase activity compared to wheat, contributes to the faster or higher breakdown of phytic acid. And in fact, the phytic acid was broken down the most in all eight wholemeal wheat breads in this optimized sourdough process, the phytic acid concentration was less than 10% compared to wholemeal flour. This underscores that the recipe and the dough process used by the baker are the most important factors in making minerals such as Fe and Zn from grain available to us humans.

Finally, we compared the mineral concentrations in the flour with those in the bread in the spelt study with five dough runs (Table 1). The bread contained at least as many minerals as the flour. We also did not find any differences in the mineral concentrations between the yeast dough and sourdough versions. On the other hand, there were differences between the starting flours (three different types of spelt) and the breads baked from them. This proves that the selection of varieties with a higher concentration of minerals can certainly lead to bread with a higher concentration of minerals, which is then also available for us humans through appropriate dough processing.

In summary, we were able to show that the mineral concentrations vary greatly depending on the type of grain selected and even within the type depending on the type selected, and that the availability of minerals bound in the phytic acid complex is particularly influenced by the baker’s recipe and dough process.
Our research along the value chain has again shown that for a healthier diet for the world population, for example to we have to think and act more holistically. For illustration, in Fig. 4 we have sketched the bread value chain, which starts with the breeding of a new wheat variety, which a farmer grows, the miller processes and the baker turns into the final product that we humans then consume. All partners in the value chain have an influence on the amount of minerals such as Zn that is ultimately available to us in the bread. First of all, the raw material, e.g. a batch of wheat grains, must contain as much Zn as possible, which can be influenced by the choice of variety. Despite the choice of variety, grain grains with different mineral content arrive at the miller depending on the cultivation location. This can hardly be influenced, but the mineral content should be checked with the help of rapid tests that are yet to be established. In addition, the minerals should not be “ground away” either, as there are only fractions of the amount of minerals in the light-colored flour compared to the wholemeal flour. Finally, the baker must also choose suitable recipes, such as a long yeast dough or a sourdough starter with wholemeal rye flour, so that minerals such as Zn

and Fe from wholemeal cereals are available to us humans in the bread So far, very little of this has been taken into account, in baking the determination of quality focuses solely on maximizing the bread volume with light flours.

Dough processing as a means of optimizing bread quality?

Previous studies have already shown that the dough process has a significant influence on a wide variety of ingredients and bread properties. In comparison to direct yeast dough, a long yeast dough process means that the bread retains its freshness and tastes better, sometimes with a slightly reduced baking volume (Rapp et al 2017, Longin et al 2019). At least 20% of all proteins that can be measured in bread today are also influenced by the dough process (Zimmermann et al 2021). The content of FODMAPs (fermentable oligo-, di- and monosaccharides and polyols) in bread is also strongly influenced by the dough process (Ziegler et al 2016, Longin et al 2020).

In our spelt baking study (test series 3), we measured the sugar alcohols, mono-, di- and oligosaccharide contents in the flours and breads of the different dough methods (Tab. 2). It was confirmed that the dough process is an important factor in influencing the sugar components in the bread. The FODMAP levels in bread, which are mainly determined by the amount of oligosaccharides (including fructans) and excess fructose, were reduced the most by using sourdough, which other studies have already reported (e.g. Grausgruber et al 2020). It's worth taking a closer look. While the levels of oligosaccharides, excess fructose and maltose were lower in the sourdough breads, the mannitol level, for example, was higher compared to the yeast breads. The extent to which these sugar components influence the digestibility of bread is still a matter of debate in medical research. In a current human study on the digestibility of various breads in patients with possible wheat sensitivity/irritable bowel syndrome, gluten-free bread with a very high added amount of oligosaccharides was best tolerated (Zimmermann et al 2022). It is also important to remember that oligosaccharides such as fructans are counted as dietary fibers and that we humans should eat more of them. In addition, determining the oligosaccharides in grain is difficult. The total content of oligosaccharides includes not only indigestible but also digestible types such as maltodextrins. So one can only say something about the wholesomeness of bread based on the sugar content alone, but these sugars also have other effects, e.g. in the dough, where they influence fermentation processes, or in the aroma formation in the final bread.

Acrylamide is a substance classified as a carcinogen that can be formed when starchy products such as potatoes and cereals are processed when exposed to high heat (Claus et al 2008, Huang et al 2015). Fried potato products such as crisps and French fries in particular show high concentrations of acrylamide, but acrylamide can also be found in most cereal products detected, but in higher concentrations mainly in biscuits, gingerbread and crispbread. In bread, over 95% of the acrylamide is found in the crust and therefore hardly any acrylamide in the crumb (Claus et al. 2008). We measured the acrylamide levels in the bread crusts of the spelt baking experiment (test series 3) (Table 1). These were influenced by the dough process and the choice of variety. If you compare the three types of spelt with each other, the acrylamide levels in the bread crusts were stable across all dough processes, lowest in spelt type 2 and highest in spelt type 3 potential acrylamide levels in the end product, which could then best be selected via the amount of free asparagine in the variety flours (Rapp et al 2018). The influence of the dough process was consistently measurable across all three types of spelt; the long yeast dough process in particular seems to greatly reduce the risk of an increased amount of acrylamide. However, it should be emphasized that the amount of acrylamide in normal bread is rather small, since acrylamide is mainly formed on the bread crust and this has a small proportion by weight of the bread.

The individual dough guides also had a major impact on the bread quality. The aroma of bread becomes more intense and aromatic with longer dough processes (Rapp et al 2017, Longin et al 2019), which is of course significantly enhanced by the use of sourdough. The baking volume, bread crumb and bread crust quality are also significantly influenced by the different dough processes (Fig. 5). While only slight bread volume differences were visible between the individual types of spelt (test series 3) within the same dough process, a significant increase in volume could be achieved through the different sourdough processes. Of course, these baking attempts should not be overrated because of the small number of varieties. However, we do think that the trials clearly show the potential that bakers can exploit in terms of baking quality, which is at least completely neglected in many discussions about the baking quality of wheat or spelt varieties. While breeding a new variety with improved baking properties takes at least 10 years, adjusting the recipe should be the more effective way to optimize bread quality. A lot of baking quality is also achieved through the high protein content of the wheat varieties and thus the high nitrogen fertilizer requirements in agriculture. Even if the bread value chain is already very sustainable compared to other value chains such as meat and fruit, sustainability analyzes show that a reduction in nitrogen fertilization in wheat cultivation would improve the sustainability of bread the most (e.g. Goucher et al. 2017). In this respect, we want to motivate the bakers to use the potential of recipe adjustments again in the future and thus to enable adjustments of the quality requirements in terms of sustainability and security of supply to the globally scarce raw material wheat.

Conclusion

All partners in the value chain influence the final product quality. For example, we were able to show that the mineral concentration in bread can be influenced by the choice of grain type, but also by the variety within a grain type. Since a large part of the minerals is stored in the outer surface layers of the grains, the use of wholemeal flour instead of light-colored flours can be seen as a first important building block for improving the mineral supply of the population. In addition, important minerals such as Fe and Zn are bound in the grain in the phytic acid complex and are mainly available through the selection of a suitable dough process. Roughly speaking, the following trend emerges: the longer and more the total amount of flour is fermented by yeast or sourdough, the more phytic acid is broken down and minerals are available as a result. The use of raw materials with high phytase activity, such as wholemeal rye flour, can also significantly increase the availability of minerals to enhance. We were also able to demonstrate the importance of all partners in the value chain for other ingredients and baking quality properties.

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Fig. 1: Mineral concentrations in wholemeal flours of 13 different types of wheat, spelt, emmer and einkorn. The variety values are mean values from three different growing environments (trial series 1).

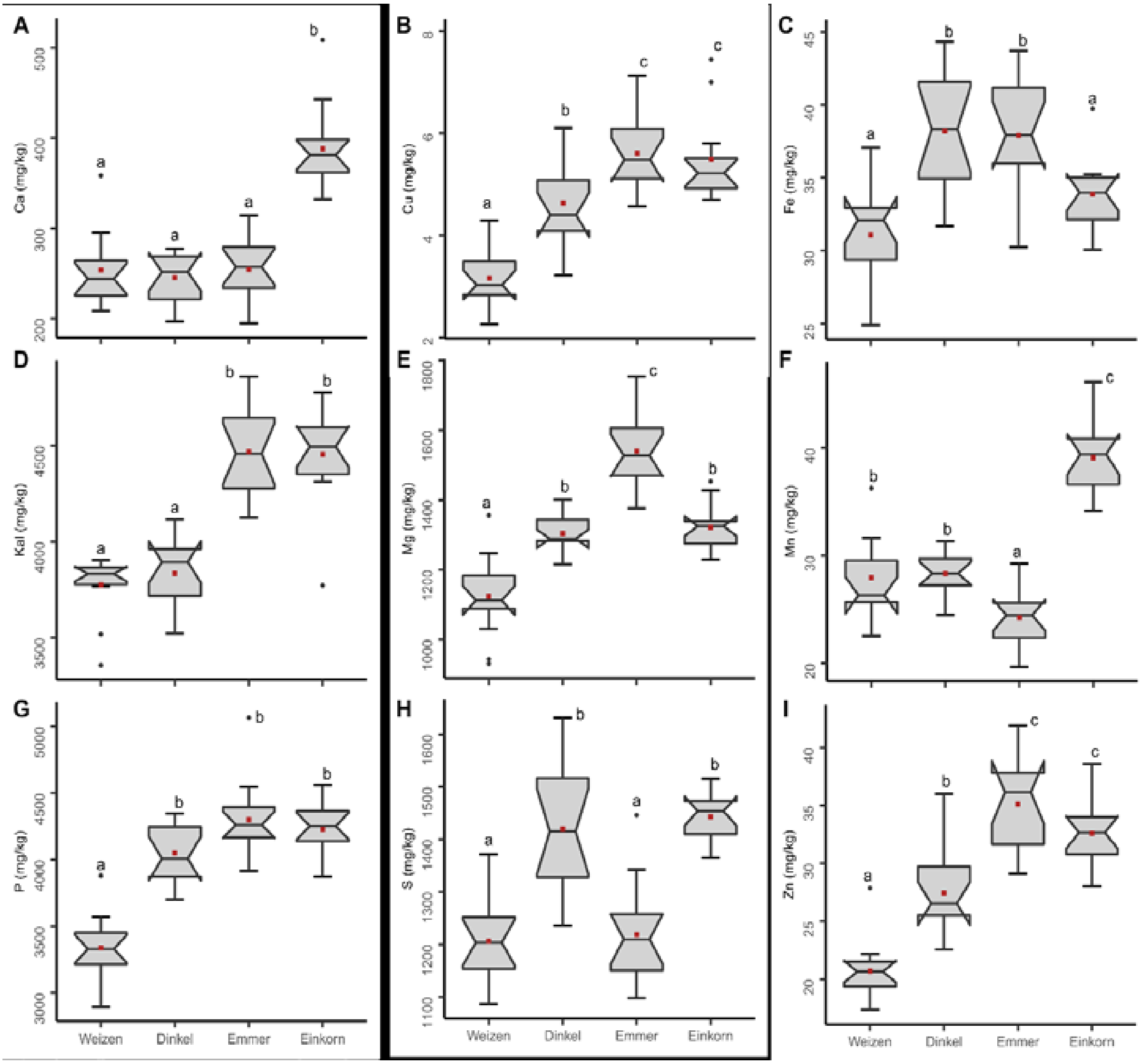

Fig. 2: Phytic acid concentration (A), phytase activity (B) and dietary fiber content (C) of eight types of wheat, spelt, emmer and einkorn (test series 2).

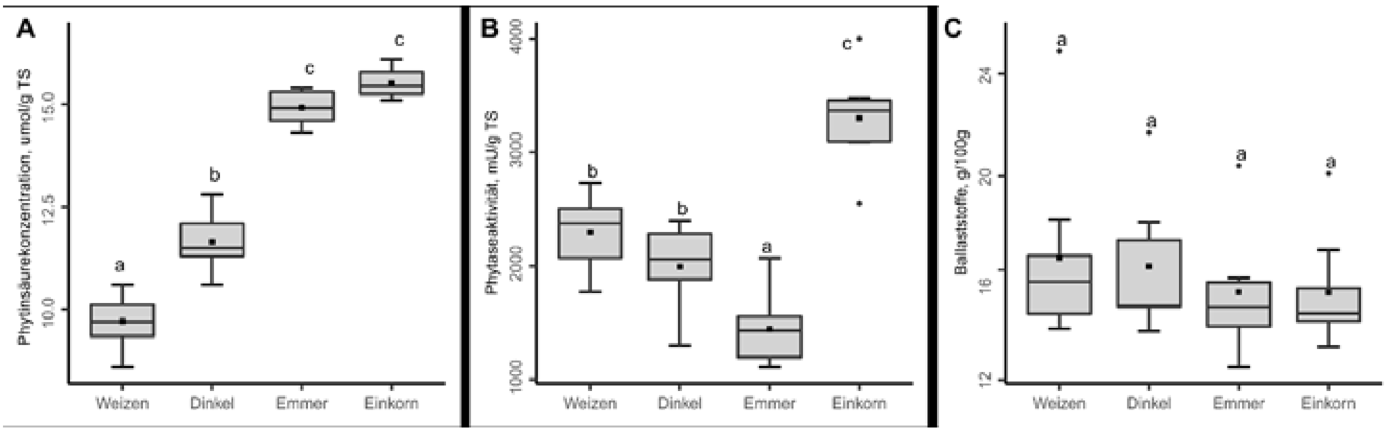

Fig. 3: Phytic acid concentrations in whole grain breads made from three types of spelt baked in 5 batches (A, experimental series 3) and eight types of wheat baked in three batches (B, experimental series 2). ST-Det1Step = Detmolder 1 step sourdough, ST-Salt = Monheimer Salt sourdough, ST-Berliner = Berlin short sourdough, ST + rye = Detmolder 1 stage sourdough with standard rye flour

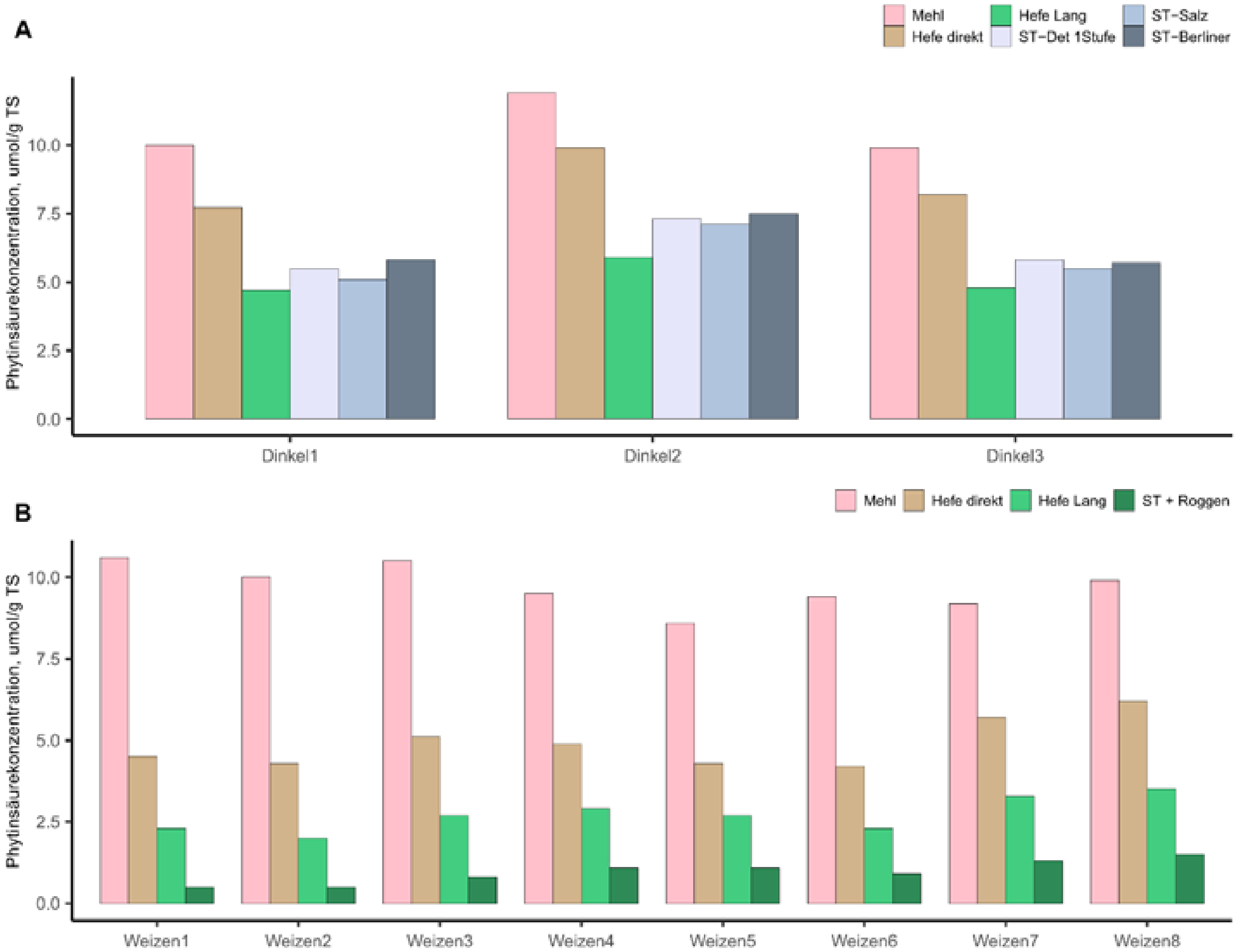

Fig. 4: Mineral concentration and availability in our diet depends on all partners in the value chain

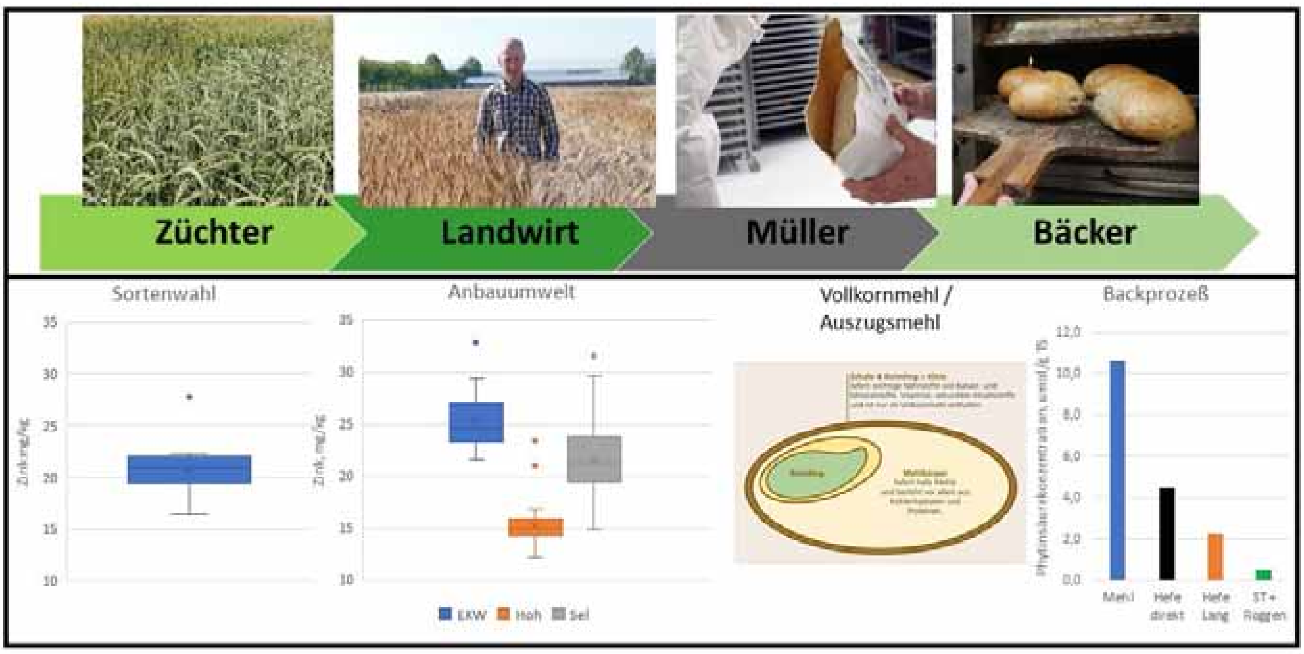

Fig. 5: The loaves of test series 3 differed significantly in shape, volume and height/width ratio depending on the dough process

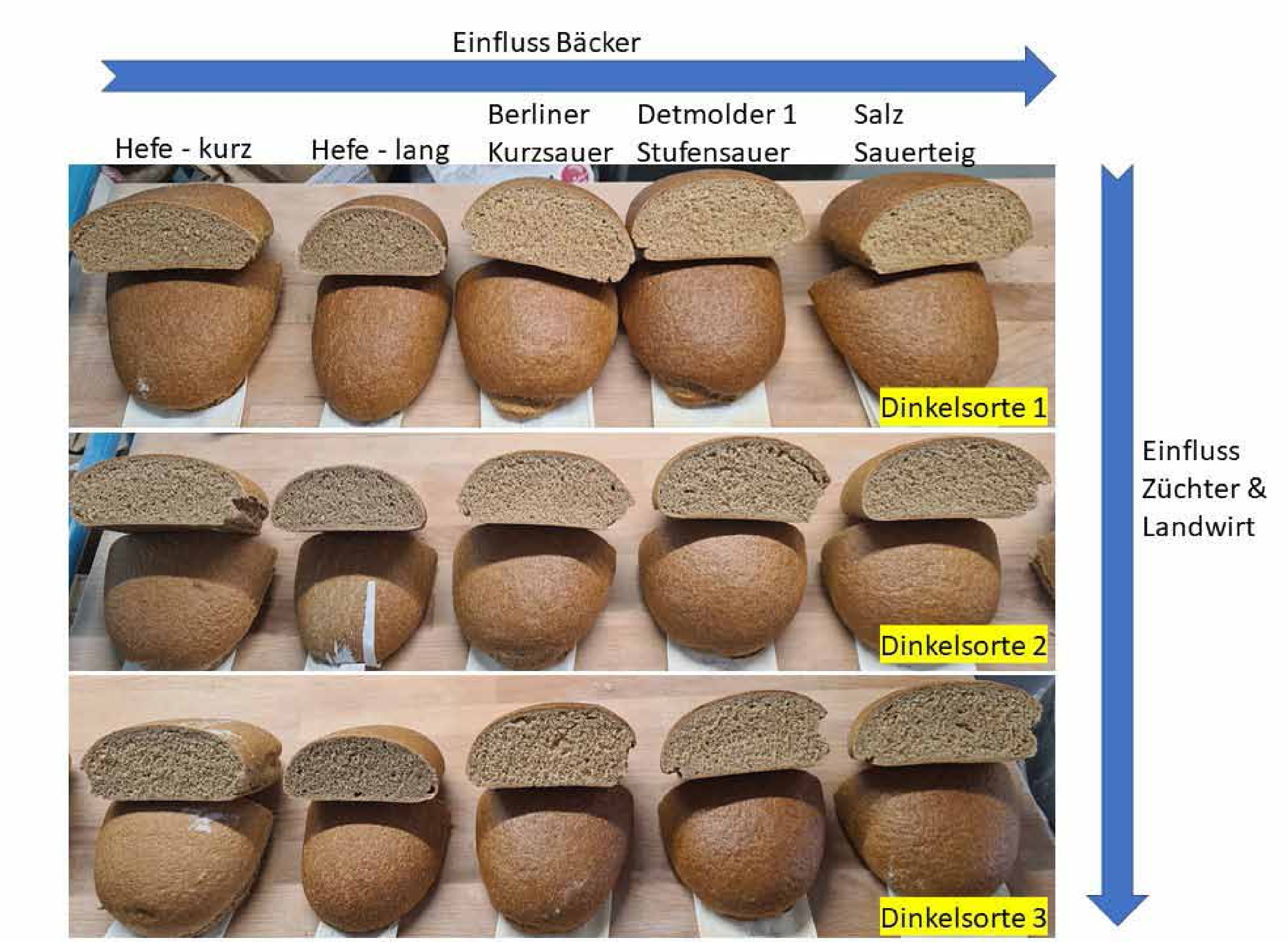

Table 1: Concentrations of acrylamide (ug/kg), phytic acid (umol/g) and minerals (mg/kg) in flour and bread from three types of spelt (test series 3; ST-Det1Step = Detmold 1-step sourdough, ST-Salt = Monheimer Salt sourdough, ST-Berliner = Berlin short sourdough)

Teigführung	Sorte	Acrylamid	Phytinsäure	Ba	Ca	Cu	Fe	K	Mg	Mn	Na	P	S	Zn
Mehl1	Dinkel1		10,00	1,08	223,78	3,96	29,98	4262,88	1007,25	24,26	NA	3590,69	1079,86	17,11
Mehl2	Dinkel2		11,90	0,72	218,21	5,03	39,84	4316,68	1165,46	27,86	NA	3939,73	1249,13	20,32
Mehl3	Dinkel3		9,90	1,04	254,77	4,14	27,69	4241,06	940,78	20,41	NA	3451,34	1078,37	18,41
Hefe direkt	Dinkel1	346	7,70	1,18	331,87	4,06	39,49	4571,29	1082,78	25,07	7446,85	3931,04	1226,53	20,97
Hefe lang	Dinkel1	89	4,70	1,16	316,54	3,94	36,58	4383,47	1047,15	24,61	7521,16	3797,35	1258,87	18,47
ST- Det 1Stufe	Dinkel1	442	5,50	1,19	319,71	4,08	32,88	4511,04	1068,55	25,06	7946,59	3867,23	1226,07	20,37
ST-Salz	Dinkel1	440	5,10	1,17	317,95	4,07	32,30	4557,58	1058,07	24,66	7777,15	3869,86	1232,17	20,41
ST -Berliner	Dinkel1	336	5,80	1,25	323,57	3,94	33,55	4540,08	1063,63	24,96	7317,78	3875,67	1205,74	20,20
Hefe direkt	Dinkel2	290	9,90	0,80	319,88	5,33	41,92	4579,59	1212,09	28,20	7834,64	4232,76	1429,24	24,31
Hefe lang	Dinkel2	39	5,90	0,82	321,56	5,55	41,97	4462,58	1208,64	28,43	7499,25	4171,91	1471,37	22,49
ST- Det 1Stufe	Dinkel2	344	7,30	0,82	315,68	5,33	41,49	4589,32	1221,56	28,46	6958,70	4253,44	1432,23	23,85
ST-Salz	Dinkel2	224	7,10	0,84	319,43	5,31	41,34	4586,17	1217,81	28,18	7183,17	4248,66	1469,38	23,85
ST -Berliner	Dinkel2	274	7,50	0,83	314,43	5,26	40,18	4498,06	1173,99	27,62	7231,20	4127,25	1440,27	23,69
Hefe direkt	Dinkel3	440	8,20	1,21	360,24	4,68	31,09	4700,83	1035,67	21,81	7347,51	3848,66	1243,74	23,08
Hefe lang	Dinkel3	97	4,80	1,23	357,79	4,62	31,99	4551,07	1011,81	21,71	7691,79	3750,48	1304,60	20,35
ST- Det 1Stufe	Dinkel3	524	5,80	1,24	360,28	4,79	31,91	4654,63	1047,16	22,27	7736,70	3852,48	1269,00	23,47
ST-Salz	Dinkel3	594	5,50	1,19	348,62	4,44	29,56	4557,32	996,64	20,95	7246,28	3715,59	1230,49	21,62
ST -Berliner	Dinkel3	752	5,70	1,25	359,62	4,60	31,50	4786,20	1061,45	22,45	7611,23	3933,48	1245,17	22,47
Mittelwert Mehl			10,60	0,95	232,25	4,38	32,50	4273,54	1037,83	24,18	NA	3660,59	1135,79	18,61
Mittelwert Brot			6,43	1,08	332,48	4,67	35,85	4568,62	1100,47	24,96	7490,00	3965,06	1312,32	21,97
ttest			0,01	0,37	0,01	0,48	0,47	0,00	0,45	0,76	NA	0,16	0,07	0,05
Mittelwert Hefe-Brot		216,67	6,33	1,07	334,65	4,70	37,17	4541,47	1099,69	24,97	7556,87	3955,37	1322,39	21,61
Mittelwert ST-Brot		436,67	6,87	1,09	331,03	4,65	34,97	4586,71	1100,98	24,96	7445,42	3971,52	1305,61	22,21
ttest		0,03	0,45	0,85	0,73	0,88	0,40	0,42	0,98	0,99	0,41	0,88	0,77	0,57

Table 2: Contents of sugar alcohols, mono-, di- and oligosaccharides in mg/100g in flour and bread from three types of spelt (test series 3, ST-Det1Step = Detmold 1-step sourdough, ST-Salz = Monheim salted sourdough, ST-Berliner = Berliner short sourdough)

Teigführung	Sorte	Erythritol	Xylitol	Arabitol	Ribitol*/ Galactitol / Sorbitol	Mannitol	Arabinose*/ Rhamnose	Galactose	Glucose* / Sucrose	Mannose	Fructose	Lactose	Maltose	Gesamt-Oligos	Excess Fructose	FODMAPs
Mehl1	Dinkel1	3,70	0,00	1,47	20,22	1,80	0,62	2,91	108,48	0,00	20,25	4,78	73,23	4178,33	0,00	4210,29
Mehl2	Dinkel2	2,54	0,00	0,71	16,28	2,08	0,31	2,06	81,31	0,00	19,03	2,89	76,58	3335,80	0,00	3360,30
Mehl3	Dinkel3	2,47	0,27	1,80	19,28	2,62	0,39	2,83	99,42	0,00	18,80	4,65	68,41	3661,16	0,00	3692,25
Hefe direkt	Dinkel1	13,61	1,44	0,05	12,16	2,78	2,72	14,09	223,52	8,91	641,06	13,33	1103,59	2791,74	417,54	3252,66
Hefe lang	Dinkel1	39,95	5,01	2,80	4,29	1,50	9,05	30,08	315,36	13,93	714,96	22,45	1323,19	2986,61	399,60	3462,21
ST- Det 1Stufe	Dinkel1	37,70	4,62	2,01	7,96	93,85	6,13	15,99	143,81	6,97	412,49	18,44	335,04	2010,63	268,68	2443,90
ST-Salz	Dinkel1	33,21	4,60	1,94	2,35	99,26	6,10	17,29	130,05	5,83	416,54	14,85	337,02	2109,02	286,49	2551,72
ST -Berliner	Dinkel1	34,06	4,98	2,36	10,98	86,13	4,94	22,18	186,92	9,37	527,00	19,57	472,18	2148,43	340,08	2646,60
Hefe direkt	Dinkel2	18,84	4,28	2,55	19,82	2,22	3,56	18,00	191,85	10,51	586,44	16,54	1054,16	2139,37	394,59	2598,22
Hefe lang	Dinkel2	37,98	5,69	2,94	7,61	2,51	11,75	34,43	254,13	18,32	577,48	31,68	1199,00	2691,61	323,35	3103,36
ST- Det 1Stufe	Dinkel2	47,53	5,20	2,83	2,57	95,57	9,80	21,07	139,52	7,24	413,69	27,07	432,96	1741,61	274,18	2196,56
ST-Salz	Dinkel2	37,51	4,86	2,42	2,62	91,84	8,48	18,82	124,88	7,18	361,27	24,62	370,85	1761,00	236,39	2161,25
ST -Berliner	Dinkel2	24,10	3,28	1,12	2,38	73,63	4,81	20,94	102,31	7,55	318,19	15,56	341,15	1878,17	215,88	2214,12
Hefe direkt	Dinkel3	21,52	4,86	2,82	0,00	2,07	3,58	14,20	262,76	7,73	729,68	29,22	1150,99	2460,32	466,92	2987,73
Hefe lang	Dinkel3	45,81	5,14	2,56	5,32	2,19	9,93	24,26	260,66	10,65	601,88	29,22	1074,78	2667,24	341,22	3098,68
ST- Det 1Stufe	Dinkel3	42,76	4,56	2,40	1,16	93,04	8,91	16,33	196,33	5,73	506,24	27,14	381,32	1758,18	309,91	2239,15
ST-Salz	Dinkel3	44,57	5,68	2,80	2,05	93,16	9,01	17,08	193,68	5,70	536,80	24,15	435,10	1802,65	343,11	2318,18
ST -Berliner	Dinkel3	42,23	5,70	2,76	2,51	93,22	7,36	24,35	193,29	8,30	557,46	22,50	521,26	1886,27	364,16	2419,36
Mittelwert Mehl		2,90	0,27	1,33	18,59	2,17	0,44	2,60	96,40	0,00	19,36	4,11	72,74	3725,09	0,00	3754,28
Mittelwert Brot		34,76	4,66	2,29	5,98	55,53	7,08	20,61	194,61	8,93	526,75	22,42	702,17	2188,86	332,14	2646,25
ttest		0,00	0,00	0,07	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,03
Mittelwert Hefe-Brot		29,62	4,40	2,29	8,20	2,21	6,77	22,51	251,38	11,67	641,92	23,74	1150,95	2622,81	390,54	3083,81
Mittelwert ST-Brot		38,19	4,83	2,29	3,84	91,08	7,28	19,34	156,76	7,10	449,97	21,55	402,99	1899,55	293,21	2354,54
ttest		0,19	0,54	0,99	0,20	0,00	0,77	0,42	0,00	0,03	0,00	0,54	0,00	0,00	0,00	0,00