Breeding of high quality wheat for organic agriculture

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1. Summary

New cultivars of wheat, specially those suitable for organic agriculture, must meet very high quality demands. Limited resources available in organic agriculture restrict yield and quality potential. At times in organic agriculture, well-adapted plant types differ significantly from cultivars used in conventional farming. Organic and conventional agriculture show different demands for new cultivars. This article presents a breeding project that meets the prevailing circumstances of organic agriculture. The breeding process has been implemented under relatively extensive conditions. A breeding process can be achieved despite the oppositional roles of yield and quality while maintaining respect to the plant as a whole and the appropriate adjustment of the selection criteria. The newly available cultivars allow a production of quality wheat on any organic site.

2. Introduction

Consumers and processors expect a superior quality of biologically produced products regarding liveliness, flavour and process technology. From the view of bio-dynamic agriculture food should holistically nourish humans. In order to meet those expectations, food has to activate the organism, enabling it to develop its physical, emotional and spiritual abilities. However, the increase of quality comes together with a decrease in quantity; quality consciousness is mostly negatively correlated with a price consciousness. These facts turn the release of a new cultivar into a challenging task.

The yield potential of organic farms is approximately 70-85% of comparable conventional farms. Mainly the lack of mobile nitrogen in the soil causes a decrease of baking quality for conventional varieties used on organic sites. Additionally, there are stronger plant-environment interactions in organic than on conventional sites. This is due to the restricted use of external resources (fertilizer, pesticides). Species-appropriate livestock husbandry requires a larger amount of straw which causes a need of long-straw varieties. This subsequently diminishes weeds.

3. Proceeding

3.1. Expectations and Weighting of Criteria

3.1.1. Consumers criteria

Liveliness / nutrition quality	*Weight (relative to conventional varieties)*
free from fusarium toxins	=
tolerability / allergenity	+++
pattern of amino acids	+?
Liveliness / vitality (e.g. based on Image Creating Methods)	++
sensorial quality (aroma + taste)	+++

3.1.2. Processing criteria

Technological quality	*Weight (relative to conventional varieties)*
falling number	=
Protein content	+
Zeleny/SDS-Sedi	+
water absorption	+
wet gluten content	+++
gluten index	(-)
RMT volume	++
farinogram	++
extensogram	++

3.1.3. Cultivators criteria

Agronomical criteria	*Weight (relative to conventional varieties)*
grain yield	=
straw yield	++
weed competition/vegetative vitality	+++
weeding (harrow) and hoeing compatibility	+++
drought resistance (water efficiency)	++
nutrition absorption and efficiency (N, ...)	+?
mildew	- -
stripe rust	=
leaf rust	(-)
Septoria tritici	(-)
Septoria nodorum (on leaf and head)	=
Fusarium spp.	=
Seed-born diseases [loose smut, stinking smut]	+++

3.2. Practical Approaches

3.2.1. Breeding Approaches

The whole breeding progress has been carried out under organic conditions. Neither greenhouse cultivation nor winter generations in southern regions have been applied. There are two main sites for wheat breeding (Seegräben and Rheinau) and two additional locations as testing environments. The environmental conditions differ greatly from each other:

Seegräben
- close to the lake “Pfäffikersee”, min. 1000mm rainfall p.a.
- sandy clay on glacier moraine
- grassland farm with not more then 30% fieldcrop production in crop rotation
- high diseases pressure concerning leaf and ear diseases

- organic wheat yield potential 4,5-5,0 t/ha

Rheinau
- sandy soil with a great structural share of Rhein rubble, low water bonding capability
- Crop farm with less than 25% grassland share in crop rotation
- 600mm rainfall p.a., irrigation needed
- high disease pressure concerning leaf rust and Septoria nodorum
- organic wheat yield potential 4,0 t/ha

Montezillon
- Jura, 750m amsl
- mixed farming with 30% grassland share in crop rotation
- organic wheat yield potential 4,0 t/ha

Vielbringen
- Aare valley near Berne, 560m amsl
- sandy clay on glacier moraine
- mixed farming with 30% grassland share in crop rotation
- organic wheat yield potential 5,0 t/ha

A bulk breeding method is applied: Every crossing is carried out on open land. Populations are put in bulk plots, line selection starts in F4, the first line evaluation is carried out at two locations, and the subsequent checks are evaluated on at least four locations. Dimension of the breeding program: annually about 100-150 crossings, 2500-3000 F5 to F7 lines in breeding nursery, 250-400 lines in first line evaluation , 80 lines in second year evaluation and 32 lines in third and following years evaluation; approximately two cultivar releases per year.

The visual field selection is carried out in one to three runs. The single threshed ears have to pass a very strict second selection based on kernel type. Starting with the first line evaluation, technological baking quality is examined mainly based on wet gluten content (NIR or Glutomatic) and gluten index.
In the following generations, approximately 50 agronomical criteria and 7-9 quality characteristics (crude protein, Zeleny, water absorption, falling number, wet gluten, dry gluten, gluten index) are evaluated and calculated into a baking quality index (BQI). Concerning the values of crude protein, Zeleny sedimentation, wet gluten and water absorption we set up our own NIR calibration since standard calibrations are not suitable for organic wheat.

The harvest of advanced lines undergoes standardized baking tests followed by a tasting to assess the sensorial properties (aroma, taste, texture). Additionally, Visualising Methods are conducted.

3.2.2. Development of an Ideotype and Visualisation of the Plant Model
During wheat breeding, the most important decisions are made at a time when no empirical data are available. At this time the "breeder's view" is the only approach for an efficient selection and for planning crossings if such new lines are used.

The "breeder's view“ includes a vital and holistical relationship between breeder and plant, it extends the scientific knowledge and it provides also a source for future visions of agriculture in cultural development. At the first time the "breeder's view" is naturally affected by subjective expectations and abstract ideas. With growing breeder's experience and especially well-directed training, however, may objectize the „ breeder's view“. A widely differing, dynamic concept is just as well a basis of decision-making as hard facts drawn from data analysis.

Yet such a concept is not easy to communicate. For this quality wheat breeding program, a plant model was developed including various criteria: plant architecture, morphology, plant development, yield physiology, plant esthetics and processing and health criteria of the final food product. Almost each of those elements are directly accessible for visual observation or, if not so, can be experimentally understood.

The training starts with studying the plant development in different environments and examinating the environmental effects on the varieties' properties by simple comparison. In a further step, the findings are integrated in a dynamic idea. Architecturally, morphologically and physiologically optimized plant types can be designed because plant-environment interactions are less disturbed in organic farming by external inputs (eg., fertilizer). By assembling the image of the model with the plant in the breeding nursery, the real plant is obtained like a trace of chalk on the blackboard is transformed into a circle only when the the circle is imagined inside of the observer. This "model imagination" enables the breeder not to primarily focus on certain criteria but rather to look at the whole plant type and work with a more secure and efficient style.

3.2.3. Important Elements of the Plant Model

Development Phase	Elements of the Plant Model
germination	- quick germination - high vigour - low sensitivity to soil- and seed-born diseases - quick and intense rooting
tillering	- straight growth (weeding and hoeing compatibility) - high root activity (weed-competition)
stem elongation - flowering	- plenty of leaf mass and vegetative vitality - stem length 105-135cm - health (adult resistance/tolerance, i.e. every leaf disease is desired in a small amount)
development of fruit - ripening	- remobilization in leaf and stem, translocation, obvious ripening, change of colour - long last internode, loose ear - healthy ear (fungal infections undesired)
grain	- fully developed, glassy grain with intense colouring - high hectolitre mass, possibly limited grain size - healthy grain (Fusarium spp. etc.) - high wet gluten content, gluten index max. 70- 80
flour	- pearl/semolina-like, not dull or flaky

dough	- smooth and plastic, not short or woolly
bread	- sufficient volume and constancy - characteristic, complete, not flashy taste - balanced nutrition effect - dietary effect/ tolerance

3.2.4. Extended Quality Analysis

Baking tests with sensory- methods

The breads made in a standardised baking procedure are rated on a technological and a sensorial basis. The test results are visualised in a spider chart. Though grown on different sites and equipped with different protein and gluten contents, there are varieties with almost identical baking behaviour. However, there are also varieties sensitive to changing locations. In this case, the site has a large effect on the aroma and flavour properties of the bread. The variety has also an impact on the sensory properties of the bread. Some varieties show a very stable sensorial pattern on all locations. The primary aim is to detect and eliminate types with one-sided unpleasant properties.

Visualising methods (Bildschaffende Methoden)

For Visualising Methods, whole grain flour is dissolved in a certain medium and exposed to different visualising processes (i.e. copper chloride crystallisation, capillary rising pictures according to WALA and the Chroma test). In a subsequent step the pictures are interpreted and rated. A reliable evaluation requires a significant amount of experience and an excellent knowledge of the examined plant's physiology. An extra set of varying substrate concentration levels and aging serials are made to more precisely examine the product.

Considering all aspects of form, ripening, degradation and vitality we can rank wheat varieties and are able to compare them over location and year. Perennial results of the varieties show a relatively stable order which is weakly correlated to yield but to the baking quality index.

4. Results and Discussion

4.1. Official Quality Rating

In the official German wheat cultivar tests, the variety WENGA overtopped the former best cultivar Bussard with respect to baking volume, wet gluten content and water absorption. Compared to Bussard and Naturastar WENGA shows increase in the following process technological properties:

Quality criteria	compared to Bussard	compared to Naturastar
protein	+1.0% (rel. +9.3%)	+1.0%
wet gluten	+1.9% (rel. +8.8%)	+1.6%
sedimentation	+7ml (rel. +21%)	+10ml
water absorption	+2.0% (rel. +3.1%)	+1.0%
volume RMT	+25ml (rel. +4.1%)	+40ml

WENGA shows compared to the standard cultivars Bussard and Batis and to Naturastar a significant quality increase. WENGA is a variety excellently suited for production of baking wheat

on light (sandy) soils and extensively cultivated land. It may also be used as an add-in to batches with low gluten contents.

The variety ASZITA outreached the standard cultivar Bussard under organic conditions by far.

Quality criteria	compared to Bussard
protein	+1.4% (rel. +13.4%)
wet gluten	+6.6% (rel. +31.5%)
water absorption	+4.3% (rel. +7.4%)
volume RMT	+25ml (rel. 3.8%)

According to the official quality categorisation, ASZITA is rated a B-wheat (3rd class). This is due to the fact that data is drawn from conventional tests where ASZITA shows a considerable decrease in gluten strength with rising N input. Based on the results of the organic special tests, ASZITA is to be considered an E-wheat (1st class): there was not a single case when its quality would drop below the Bussard values. Hence, ASZITA is suitable as add-in wheat for quality improvement. Tests show that for batches with low gluten contents disproportionate improvements can be achieved by an additive of 10-15% of ASZITA. ASZITA provides framers the option to produce high quality bread wheat under extensive conditions, if used as mixing partner. ASZITA's weakness in yield is fully compensated by choosing a higher yielding B-wheat as a mixing partner.

According to the official Swiss quality tests who are based on intensive laboratory and baking tests the varieties POLLUX, ATARO and CLIVIO are rated as class 1 wheat. Newer varieties WIWA, SCARO, LAURIN, CASSIA and TENGRI were qualified as members of the TOP class.

4.2. Yield and Agronomical Criteria

The organic field trials have a yield spectrum of 3.5 to 5.5 t/ha and are therefore comparable to most of the organic farms in Switzerland. In long-term tests the new varieties reached 101-111% relative yield compared to Swiss standards (Titlis and Arina) as well as 89-97% compared to German standards (Bussard and Batis). The new varieties are 10-20cm longer than the standards and show a better soil coverage.

In the official test results under conventional and organic growth conditions the new varietees show similar yield and better quality compared to the Swiss standard average (Runal, Tiltis, Arina). Thus these varieties reach a yield level that is not only interesting for organic but also for conventional cultivation. In addition to the high yield, these cultivars have a high hectolitre mass, a good leaf health and an excellent ear health.

Mean of 3 Year Tests (organic) in Switzerland 2006 / 2007 / 2008 by Agroscope

Variety	Yield (q/ha)	relative	Zeleny	Gluten (%)	Quality Class
Arina	44.8	100.5	56.1	27.2	1
Runal	43.9	98.5	61.4	25.9	Top
Titlis	45.0	101.1	62.1	26.5	Top
Antonius	48.4	108.7	59.3	23.9	1
Wiwa	45.5	102.2	64.4	29.0	Top

Scaro	47.4	106.4	63.4	26.2	Top
Laurin	44.5	99.7	61.3	25.3	Top
Ataro	47.9	107.4	57.7	24.7	1
Logia	45.7	102.6	57.7	23.5	1

The official German organic special test rated WENGA 6% below the yield level of Bussard. However, considering yield and wet gluten content, an important processing parameter for organic wheat, WENGA shows overall a yield increase of 1.7% compared to Bussard. Hence WENGA has a better performance than Bussard. Above all, Wenga has agronomical improvements regarding lodging, stem cracking, leaf rust, *Septoria nodorum* and mildew on the ears those are factors to guarantee a decent yield in risky areas.

ASZITA had a 9% lower yield compared to Bussard in the official organic special test. However, ASZITA met the required high demands in wet gluten and protein content in any environment. Both gluten and protein provide a quality security, which is more important than the slightly lower yield.Examining the overall benefits in organic farming reveals that ASZITA surpasses the standard variety Bussard by 2.1% in protein yield and by 17% in wet gluten yield. ASZITA is a very long and bearded variety and is therefore preferably used in extensive farming.

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