2 Wheat: More than just a Plant

2.1 Wheat History

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Common wheat belongs to the *Triticum* genus of the grass-like subfamily *(Pooideae)*. Scientists have traced its origin back to the Middle East region, particularly the valley of the Tigris and Euphrates rivers. This area was then called Mesopotamia and is now part of Iraq. A form of the grass grew in the Euphrates valley as early as 7000 BC. The Assyrians and Babylonians mentioned wheat in stone ruins dating from 3000 BC. The Chinese are recorded as cultivating wheat in 2700 BC and had developed elaborate rituals to honour it.

Today wheat covers more of the earth's surface than any other grain crop and it is the staple grain food for much of the earth's population. Even in areas where there is a long tradition of rice eating, as in North and South East Asia, there is extensive use of wheat flour for making noodles, steamed bread and other foods.

The different wheat species are classified according to their ploidy level, i.e. the number of chromosomes. Since the basic number for wheat and also barley, rye and oats, is seven, diploid wheat has 14 chromosomes (e.g. *Triticum monococcum*); tetraploid wheat has 28 (e.g. the cultivated form *Triticum durum*), and hexaploid wheat such as we know it in the form of our common wheat (*Triticum aestivum*) has 42 chromosomes.

The discovery of how this wheat originated is now regarded as one of the most important examples of the successful use of genome analysis to answer questions of evolution. By crossing diploid and tetraploid wild forms and observing the mating behaviour of the chromosomes under the microscope as evidence of homology it was possible to prove that our modern common or bread wheat has three diploid ancestors.

Along the eastern shore of the Mediterranean, through Anatolia and Mesopotamia to the Persian Gulf – the Fertile Crescent – the hybridization (crossing) of two diploid species (with 14 chromosomes each) resulted in a tetraploid species (emmer) without the intervention of man. Further hybridization of this emmer with diploid goatgrass (*Aegilops tauschii*) in about 6000 BC resulted in today's common wheat, which spread from the Arabian peninsula to the whole world.

2.2 Wheat Kernel Composition

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Wheat, like other members of the grass family, produces a one-seeded fruit that does not split open at maturity. The seed consists of germ and endosperm enclosed by a nucellar epidermis and a seed coat. A fruit coat, or pericarp, surrounds the seed and adheres closely to the seed coat. This type of fruit is commonly called a kernel or grain but is known as a caryopsis to the botanist. The longitudinal and cross-section views of a wheat kernel are presented in Fig. 1. The pericarp, or fruit coat, surrounds the entire seed and acts as a protective covering. It is composed of several layers, which are, in order, from the outside to the inside towards the centre of the kernel: epidermis, hypodermis, remnants of thin-walled cells, intermediate cells, cross-cells and tube cells. In the crease of the wheat kernel, the seed coat joins the pigment strand and together they form a complete coat around the endosperm and germ. The seed coat is firmly joined to either the cross or tube cells on the outside and to the nucellar epidermis on the inside. Three layers are distinguishable in the seed coat: a thick outer cuticle, a coloured layer containing pigment and a very thin inner cuticle. The nucellar epidermis, commonly called the hyaline layer, is a compressed cellular layer between the seed

2.2 Wheat Kernel Composition

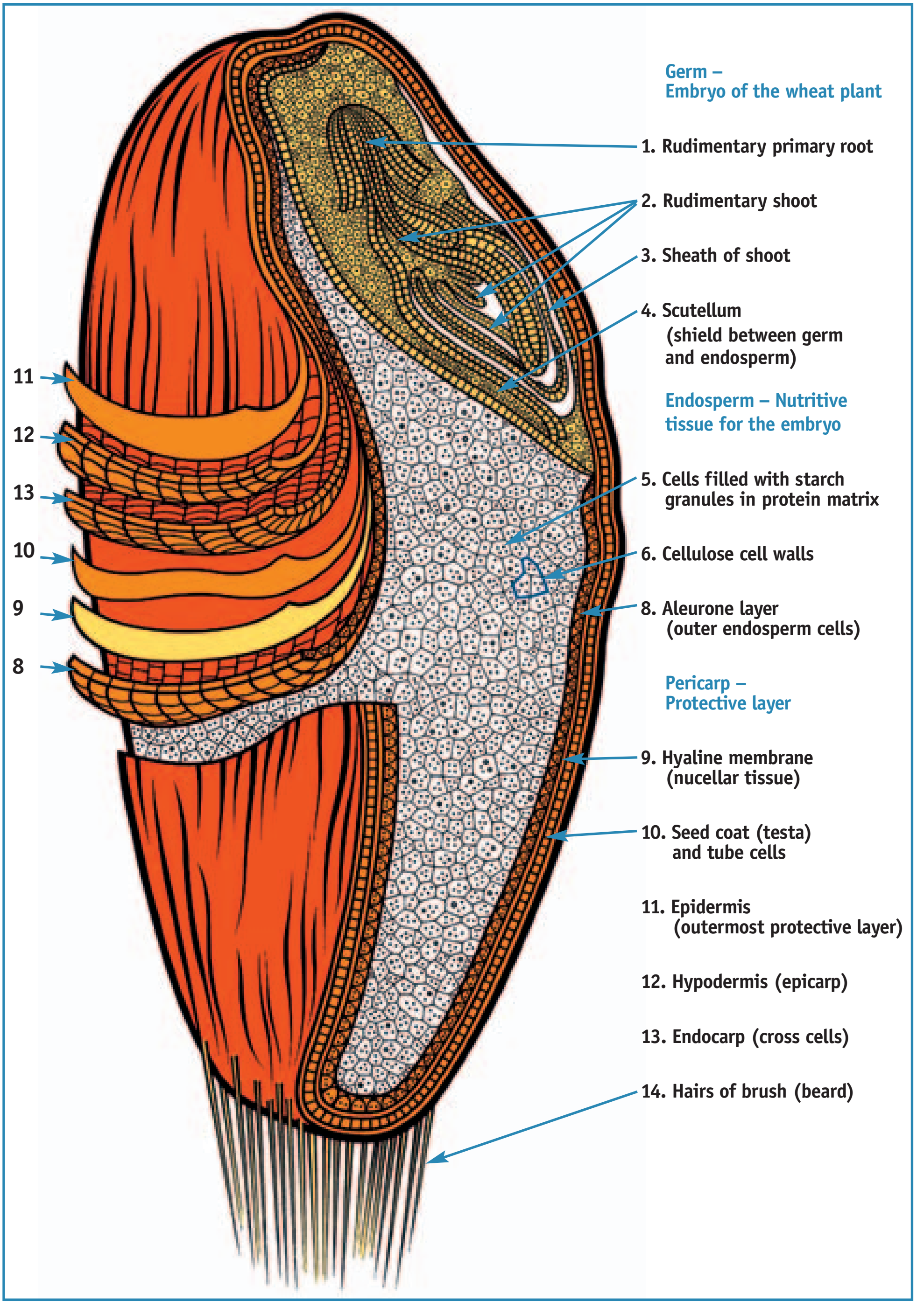

Fig. 1: Longitudinal view of a wheat kernel (modified from Berghoff, 1998)

Tab. 1: Typical composition of wheat kernel fractions[a] (% d.b.)

Parameter	Whole wheat	Pericarp	Aleuron layer	Bran[b]	Starchy endosperm	Germ
Weight	100	9	8	17	80	3
Ash	1.5	3	16	9	0.5	5
Protein	12	5	18	11	10	26
Lipids	2	1	9	5	1	10
Crude fiber	2	21	7	14	> 0.5	3
Other carbohydrates[c]	82	70	50	61	88	56

[a] *Modified from Pomeranz, 1987*
[b] *Includes pericarp and aleuron layer*
[c] *Calculated*

coat and the aleurone layer and closely united to both. Botanically, the aleurone layer is the outer layer of the endosperm but to most millers it is considered part of the outer structure of the wheat kernel commonly called bran. Bran (pericarp plus aleurone layer) makes up about 17% of the kernel weight and contains about 9% ash, almost 20 times more than the ash content of the endosperm (Tab. 1).

The starchy endosperm is composed of three cell types. Peripheral cells are located just inside the aleurone layer and are equal in diameter in all directions. Prismatic cells, located inside the peripheral cells, are radially elongated towards the centre of the kernel. Central cells are located inside the prismatic cells and are irregular in size and shape. The starchy endosperm is the source of flour and is estimated to constitute 74.9 - 86.5% of the kernel weight. Its cells are packed with starch granules embedded in a protein matrix. Two types of endosperm protein have been identified. The first is salt-soluble albumans and globulins, equated with functional cytoplasimic and membrane protein. The second is gluten-forming gliadin and glutenin, which are storage proteins. The storage proteins in wheat are unique in the plant world; upon wetting, these proteins yield a viscoelastic substance called gluten. The gluten produces the strong elastic dough that is required for yeast-leavened products such as bread and rolls. A decrease in both the endosperm protein and the mineral (ash) content is observed from the outside to the centre of the kernel.

The germ is the embryo or sprouting section of 30
the seed, which is composed of two major
parts. The first is the embryonic axis, which is 54
made up of the rudimentary root and shoot. The second is the scutellum that functions as a storage, digestive and absorbing organ. The germ makes up approximately 2 - 3% of the kernel weight and is usually removed in the milling process because it contains lipids that limit the keeping qualities of flour.

The structure and composition of the wheat 94
kernel is responsible for its use as human food. The bran layer provides the protection needed for storage purposes. The low amount of lipids and a limited amount of lipid-splitting enzymes also contributes to storage stability. Wheat contains large amounts of starch, which represents a significant source of energy in the human diet and contributes to the 6 - 11 servings[1] identified at the base of the food pyramid (Fig. 2).

[1] *Serving sizes using USA conventional and metric measurements are as follows:*
1 slice (50 g) bread
1/2 cup (125 mL) cooked rice or pasta
1/2 cup (125 mL) cooked cereal
1 oz (28 g) ready-to-eat cereal

Although the recommendation on the composition of the diet is actually being modified, starch will still be a major part of it. The kernel structure itself has determined the methods of commercial separation into its component parts. Specifically, the light-density, tough bran and the soft, pliable germ are separated from the more dense and friable endosperm by the modern milling process.

Fig. 2: Food guide pyramid

2.3 Wheat Development in the U.S.

The wheat plant itself goes through several stages of development from the time it is planted until it has reached maturity (Fig. 3). These stages are monitored and measured at each point by farmers and researchers in an effort to understand how best to improve the amount of wheat produced by each plant. This diligence combined with experience helps the farmer to make decisions about fertilizers or other chemical applications for disease and pest control. Ultimately, the goal is a large crop of high milling quality wheat produced at the least cost.

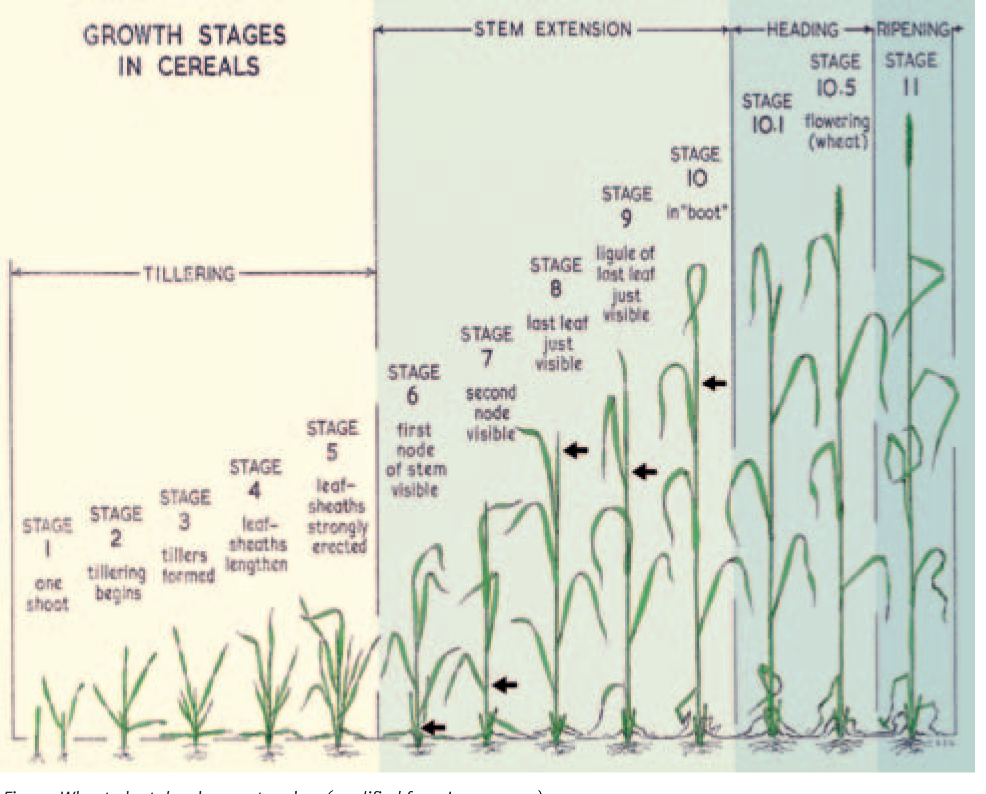

Fig. 3: Wheat plant development scale (modified from Large, 1954)

2.4 Wheat Cultivation and Harvest

Wheat planting practices and the labour required for planting have seen dramatic changes over the last century. Powerful technology - enhanced tractors and implements capable of working more than 120 acres (48.6 hectares) in a single day (Fig. 4) – have replaced men with mules in the field.

Fig. 4: Harvesting wheat with a modern combine (source: Kansas State University)

In some cases wheat is even planted over the top of the previous year's stubble using a method called "no-till" in an effort to preserve soil moisture, reduce soil erosion and lower the amount of fuel required per acre. Using modern farm equipment, wheat seeds are "drilled" or planted in narrow rows. As the wheat matures the space between the rows seems to fill with the growing plants, giving the appearance of a sea of grain. In North America, planting of winter wheat begins before September in the northern areas, and continues through October in the southern regions (Fig. 5). The harvest begins in May of the following year in the southern regions and continues well past July in the northern regions (Fig. 6). Spring wheat, on the other hand, is normally planted during the month of April with harvest taking place after the 15th of August of the same calendar year.

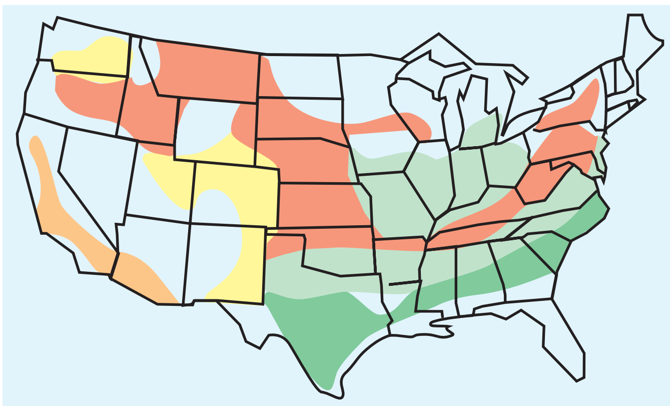

Fig. 5: Wheat planting in the United States (modified from Anon., 1993)

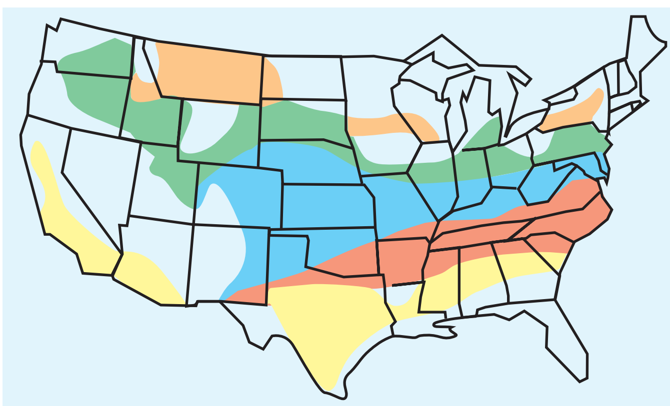

Fig. 6: Wheat harvest in the United States (modified from Anon., 1993)

2.5 Global Significance

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Cereals are the staple food of the world's entire population, albeit with great regional differences. The main products are wheat, rice and maize, that make up about 85% of the global grain harvest of about 2 billion t per annum (Tab. 2).

Netherlands, the country that achieves the highest yield per unit of area alongside Ireland. In the Netherlands it took 5 years to raise the national average yield from 5 to 6 t/ha and 10 - 12 years to raise it from 6 to 7 t/ha.

In Germany, for example, the development of wheat growing over the past few decades has been characterized by more and more intensive

Tab. 2: Cereal growing (five-year average, 1996 - 2000)[a]

Cereal	Cultivation		Yield	Harvest	
	1000 ha	% of total area	t/ha	1000 t	%
Wheat	220,178	32.1	2.69	590,975	28.5
Rye	10,266	1.5	2.12	21,738	1.0
Barley	58,952	8.6	2.40	141,555	6.8
Oats	14,312	2.1	1.95	27,920	1.3
Maize	139,626	20.3	4.27	596,469	28.7
Millet/sorghum	80,287	11.7	0.77/1.43	90,808	4.4
Rice (paddy)	153,165	22.3	3.83	585,965	28.2
Others	10,159	1.5	-	19,704	0.9
Total	**686,946**	**100**	**3.02**	**2,075,133**	**100**

[a] *Source: ZMP Market Balance 2001 (cereals, oil seeds, animal feed)*

At the International Wheat Congress in Saskatoon, Canada in 1998 it was estimated that wheat is the staple food of about 35% of the world's population and that the demand will be 850 to 1,050 mio t in the year 2020.

On the basis of a wheat harvest of 569 mio t and a global average yield of 2.5 t/ha at that time, an increase in yield of 1.6 to 2.6% p.a. will be necessary on more or less the same growing area if this demand is to be met. The increase in yield in the developing countries between 1961 and 1994 was 2% p.a.

In Western Europe and North America the yield increased by 2.7% p.a. from 1977 to 1985 and by 1.5% p.a. between 1986 and 1995. In the same periods the global increase in yield was 3% and 1.6% respectively. The conclusion to be drawn from this is that although the total wheat crop is increasing, the increase in yield is declining in both absolute and relative terms. This correlates with the results from the cultivation, chiefly in the form of shorter and more lodging-resistant varieties and the increased use of nitrogen fertilizers and highly effective fungicides. In the mid 1970s the value tests carried out by the BSA[2] – the relevant public authority in Germany – to determine productivity and the resistance and quality attributes of the wheat were conducted with 50 to 140 kg nitrogen per hectare depending on the previous crop and the quality of the site, the average being 100 kg. Today these field tests are carried out on the intensive level with 160 to 220 kg/ha, with an average of 190 kg. Through this combination of high-yielding varieties and suitable cultivation and plant protection methods, the wheat achieved yield increases of about 0.150 t/ha per annum (Tab. 3).

[2] *The Bundessortenamt (BSA) in Rettmar, Hanover, is the German agency responsible for the protection of new plant varieties.*

Tab. 3: Development of the grain yield and baking quality of German winter wheat in the period 1976 - 2001 (three-year averages of the intensive variant in VT [a] 2 or 3 of the BSA [2])

Attribute		1976-1978	1981-1983	1986-1988	1991-1993	1996-1998	1999-2001
Falling Number	s	321	306	248	306	292	287
Protein content of the grain	%	13.4	13.0	13.6	13.4	13.0	12.5
Sedimentation value	mL	31	34	36	41	45	41
Baked volume	mL/100 g	610	634	628	657	613	616
Flour yield T 550	%	75.0	76.7	76.9	77.6	77.1	79.3
Ash value	mg/100 g	675	669	649	640	696	612
Granularity	%	43	45	42	50	53	53
Water absorption	%	54.9	55.5	56.9	58.4	58.0	58.9
Grain yield	t/ha	6.5	7.7	8.4	9.0	9.6	9.9

[a] VT – value test

The quality results smoothed by calculating the three-year average for 15 to 30 varieties show some striking trends for the past 25 years. Grain hardness, that manifests itself as granularity and thus water absorption, has increased noticeably. The sedimentation value has risen appreciably without positive effects on baked volume. The protein content tends to be lower, the reason being the negative relationship between grain yield and protein content as the grain yield steadily increases.

Simultaneously with this development, plant breeders succeeded in programming more and more new breeds genetically for high flour and baking quality. As a result, there was no longer any need to process summer wheat or the usually valuable imported wheat from the USA or Canada for quality reasons. The names of varieties such as Diplomat, Kormoran, Monopol, Astron, Zentos, Bussard etc. are representative of this trend.

Besides the level and reliability of the yield as objectives of breeding, and also processing quality – chiefly understood as baking quality and more recently extended to include the special qualities "biscuit wheat" and "starch wheat" – selection in respect of the health of the plants has high priority.

A comparison of susceptibility to leaf and ear diseases shows that considerable progress has been made in breeding for resistance, but what has been achieved so far still leaves room for improvement (Tab. 4).

The interplay between the genes for resistance in the varieties and those for virulence in the disease-causing organisms is complex and differs from one disease to another. Breeding for resistance to mildew has been particularly successful. Only 10 to 20 years ago this disease was still widespread in wheat and made the use of fungicides necessary at a fairly early stage in the development of the crop. There are now a number of varieties that are practically unaffected by attack and are likely to remain healthy on a broad basis of resistance.

In the case of yellow rust the situation is similar, but with regard to its virulence the fungus is even more capable of transformation than the mildew fungus. This means that varieties that were initially resistant to yellow rust still become susceptible to the disease when a new, aggressive yellow rust strain occurs. But here, too, there are examples of long-term field resistance.
On average it has also been possible to considerably reduce susceptibility to leaf rust in

Tab. 4: Development of grain yield and agronomic and resistance properties[a] according to the year of approval in Germany

	Approval Period			
	Before 1993	1994 - 1997	1998 - 1999	2002 - 2003
Number of varieties	**21**	**16**	**19**	**25**
Grain yield	4.3	5.3	6.1	6.8
Height of plant	5.2	5.1	4.5	4.3
Lodging tendency	4.8	4.9	4.4	3.5
Mildew	4.9	3.5	2.5	2.8
Yellow rust	3.3	3.7	3.5	2.6
Leaf rust	6.5	4.7	4.6	3.5
Septoria leaf spot	5.4	4.7	4.5	4.6
HTR / DTR[b]	5.5	5.2	5.2	5.4
Glume blotch	4.5	4.2	4.4	4.3
Ear *Fusarium*	4.5	4.0	4.7	4.6

[a] *On the 1 - 9 scales high figures indicate that a group of varieties shows the character to a high degree (for diseases a high figure means a high susceptibility).*

[b] *HTR –* Helminthosporium tritici repentis *and DTR –* Drechslera tritici repentis*; leaf-spotting diseases*

the new varieties, but as there are still great differences in the degree of resistance we may expect further progress in breeding. Progress has also been achieved in respect of the other leaf diseases such as *Septoria* and DTR (*Drechslera tritici repentis*), but compared to the above these are less obvious because the genetic variance is smaller.

Very wet weather with little sunshine in the months of June and July has caused an increase in the ear diseases of wheat in recent years. The main problem in this case is the *Fusarium* fungi, which form mycotoxins damaging to man and animals as well as reducing the yield. The preference for shorter and usually more lodging-resistant wheat varieties with "short-straw genes" chiefly results in a shortening of the upper internodes; the ear comes very close to the top leaf. Short infection routes and slow drying of the ears further increase the risk of attack.
Furthermore, where resistance to ear diseases is concerned we are dealing with a polygenic system. It is the combination of several smaller positive genetic effects that keeps the ears healthy. Moreover, unlike many other diseases the different *Fusarium* types are not specific to certain species or organs. All this makes the fusariose complex as a whole very difficult for breeders to handle. But "on the bottom line" improvements are to be seen in this field too.

2.6 Future Trends

In view of the still long development period of 9 to 12 years it is essential for the survival of the breeding enterprises to foresee what demands growers, processors and consumers are likely to make on future varieties.

At present the following trends can be detected in wheat growing. In the main they have economic reasons, ignore experience in plant growing and make great demands on the varieties of the future in respect of stress tolerance in general:

- **The area used for wheat growing is increasing.**
- **Leaf crops, which are very good preceding crops for wheat, are decreasing.**
- **This will result in a steadily rising percentage of stubble wheat or even permanent wheat growing.**
- **The sowing time is being moved forward to September even in locations with mild weather conditions.**
- **Care in tilling the soil in general, and the handling of stubble in particular, is declining, and it is likely to decline even further as energy costs rise.**

A likely result of these "sins of crop rotation" is that greater demands will be made on the health of the varieties. In particular, progress in breeding will be needed in respect of the leaf diseases associated with crop succession and also the entire foot-rot complex, especially *Pseudocercosporella herpotrichoides* (stem break eye spot, strawbreaker) and *Ophiobolus graminis* (blackleg disease, take-all).

As with barley, a shift of the sowing season into September permits greater penetration of the soil by the roots during the autumn. In conjunction with mild winters, this results in a high risk of infection with viruses transmitted by soil fungi. And as with winter barley, we shall have to reckon with a similar virus that is specific to wheat and already on the advance in the countries on Germany's western borders.

2.7 New Breeding Technologies in Central Europe

In addition to the conventional methods (Fig. 7), more and more procedures based on biotechnology are becoming available to breeders for the development of new varieties. It has to be decided from the point of view of speed, reliability of selection and cost which method or combination of methods is the most promising. With all diseases that are difficult to study and record with sufficient accuracy, such as the foot-rot complex, and where there is a highly polygenic basis for resistance, as with ear *Fusarium*, and also in the case of diseases that do not normally occur in the nursery, it would seem helpful to develop molecular markers which can then be used to carry out specific selection in young generations.

Fig. 7: Castration of a wheat flower

The use of molecular markers can also considerably shorten the breeding procedure in back-crossing programmes with non-adapted genotypes, since selection can be carried out for the genome of the parent as well as for the target gene. However, a condition for this is reasonably close and evenly distributed cover of the genome by these markers.

This has nothing to do with genetic engineering in the proper sense of the term, since the latter has not yet passed the basic research stage in cereal breeding. And this situation is unlikely to change as long as the majority of consumers do not accept genetic modification and until optimized and efficient constructs are available for transformation. But in the long term genetic engineering promises to bring considerable progress in breeding through the use of genetic diversity in conjunction with the conventional methods.

Chapter 24.1 outlines the basics and the progresses made with genetic engineering.

2.8 Conclusion

From the point of view of breeding the quality characteristics have a high level of hereditability, i.e. the genes of the variety have a very strong influence on quality. For this reason there should be a long-term catalogue of breeding requirements, integrated into the development of new varieties, for use as starch, brewing or biscuit wheat on the lines of the successful selection for baking quality.

The growing of varieties tested in Germany for three years by the BSA, the resulting precise and comprehensive description of quality and consideration of these characteristics in the choice of varieties would prevent a great many of the problems that made it difficult to market the crops of the last three years.
The value of a variety is determined by a number of important growing, resistance and quality characteristics as well as by the yield. More than in the past, perhaps, there is a need to make use of these in the varieties of today and tomorrow in organic farming. Then a little less may be more in the wheat harvest as in so many other fields.

2.9 References

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