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Recent Developments in Plant Breeding from the View of Animal Nutrition

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Abstract: Presently, global food security is one of the most important challenges for human beings. Increasing human population and reduction of available land are frame conditions for such developments. Plant breeding and using the results in plant production are important potentials to improve global food security. Some years ago, genetically modified plants (gmP) made contributions to stabilize the feed and food security. Presently, the Genome Edition (GE) opens new perspectives in plant breeding. By the way of Genome Edition, it would be possible to realize breeding successes in a shorter time and to make the results available to the farmers. The paper informs about the present stage of GE, its use on farm levels and challenges for science and policy.

Keywords: Global developments, Plant breeding, genetical modified Plants (gmP) Genome Edition (GE), Composition, Feed, Food

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1. Introduction

During the last few years, we may observe some global developments, such as:

- Further increase of global population (from about 8 billion people (about 2023) to around 10 billion people in 2050+
- Dramatical global increase of consumption of food of animal origin (Flachowsky *et al.* 2019; Windisch and Flachowsky, 2021; Flachowsky and Kamphues, 2022)
- Further reduction of arable land from about 3200 (1970) via 2000 (2015) to about 1500 m^2/people (in 2050; by World Bank/FAO) and further important resources, such as fossil fuel, water for drinking and fertilizing, important plant nutrients, such as nitrogen, phosphorus, potassium etc.

- Apart from loss of arable land, there are also high losses of food along the human food chain (about 1/3 or more of the produced food along the whole food chain can be considered as food loss; FAO, 2018)
- Further increase of malnutrition and hunger in various global regions (mainly in Africa, South-East Asia and Latin America) (FAO, 2020; FAO, 2022, FAO-WFP, 2022).
- Further increase of CO_2-concentration of atmosphere (from about 316 (1950; Thompson und Roth 2019) to 413 ppm/m^3 (2020; Leopoldina 2021) with an further increase per year by 2,5 – 3 ppm/m^3.
- Dramatical changes of climate (increase of thunderstorms, strong rains, dryness etc,)
- Some new developments of Genome Editions (also known as Genetic scissor) and awarding of the Nobel-Prize for Chemistry to Emmanuele Charpentier (Germany) and Jennifer Dounda (USA) in 2020.

Table 1 summarizes some questions by the consumers to the politicians and agricultural scientists in the Past, in the Present and in the Future. There is/would be a dramatic change in questions and answers during these 100 years.

Table 1: What were the Challenges/questions of consumers, politicians and scientists in the Past, in the Present and what would it be in the Future (from 1945 – 2050)

		Year		
1945	**1975**	**2000**	**2025**	**2050**
		Consumer		
I am hungry!	**Is there any special food?**	**I am unsure?**	**How can we feed the world?**	
Is there anything to eat?	**How safe my food is?**		**Do we need animals for food production?**	
		Politicians		
Food Security		**Food Safety**	**Global Food Security**	
		Agricultural Research (Scientists)		
Increase of food production	**Food quality,**	**Food Safety**	**Food competition (Man – Animal, hef; Table 2)**	

Food – Feed competition between men and animals may be also a topic of further interest (Table 2). We have to consider the high portion of food, which may be used as feed.

Table 2: Human edible fractions (hef-values; in % of the product) of different feeds by various authors (some examples)

Feed	*CAST (Wilkinson, 2011. and Ertl et al. 2015)*	*"hef"-Values by (Ertl et al. 2015)*		
		Low	*Medium*	*High*
Barley	80	40	60	80
Maize	80	70	80	90
Wheat	80	60	80	100
Soybean	80	50	72	93
Rapeseed	20	30	59	87
Wheat bran	20	0	10	20
Maize silage	0	19	29	45
Grass and other forages	0	0	0	0
By-products of food industry	0	0	0	0

By-products of the food industry, such as cereal brands, extracted oil seed, brans, sugar beet pulp etc.

2. What are the objectives of the paper

The objective of the presentation is to summarize some recent developments in the field of Genome Editions and to take some conclusions.

Let us start with the development of the global population and the consequences for arable land per person (Table 3). The increase of global population has dramatical consequences for the area of available land per inhabitant.

Table 3: Estimation of the available arable land per inhabitant (by World Bank and FAO 2010/2011)

Year	Global Population (Billion)	Available Area **(m^2/people)**
1970	3.7	3 200
1980	4.4	2 700
1990	5.2	2 370
2000	6.1	2 275
2010	6.8	2 030
2020	7.9	1 800
2050	9.5	1 500

As a consequence of this development, the efficiency of plant production must be increased in the available area. That means, we need more efficient plants in order to increase the plant yields and to improve their composition. The contribution deals with some new developments in the field of genetic modification of plants. Table 4 summarizes some objectives and challenges for plant breeders.

Table 4: Important challenges/traits of GMP with input and output traits (by NASEM, 2016)

Plants with Input-Traits	*Plants with Output-Traits*
Biological Stress Tolerance - Microbiological Resistance - Insect-Resistance	**Increase of nutrient and energy content** - Amino acids - Major and trace elements - Vitamins - Fatty acids - Some non essential feed additives
Abiotic Stress tolerance - Dry Resistance - Water using efficiency -Coldness-, Heat- and Salt-Tolerance	**Increased feed and food safety** - Low content of undesirable substances - Low content of mycotoxins – Improved storage of feed and food
Nutrient Intake and -utilization - Nitrogen - Phosphorus - Carbon dioxide etc.	**High nutritive value** - High digestibility - High feed/energy intake
Postharvest Behavior - Microbiological Resistance - Extending of storage - Improved silage quality	**Bioenergy and industrial Bioproducts** - High efficacy - Better properties of biofuel - Co-products should be used as feed

Furthermore, we have to consider all the potentials, which influence the plant yields. The fertilization of plants with nutrients, such as Nitrogen etc. may also influence the plant yields. Carbon Dioxide is an important plant nutrient and higher CO_2-concentration in the air may also increase the plant yields.

Apart from traditional ways to increase plant yields, there are also some potentials by plant breeding. The objective of the presentation deals with new breeding methods, mainly with Genetic Modification (GM) and New Molecular Biological Techniques (NMT).

3. What is Genetic Modification (GM)?

Details of Genetic Modification of plants are given in the Textbooks written by Flachowsky, 2013; Dederer and Hamburger, 2019; Kempken, 2020; Heberer, 2021).

In short, the objectives of plant breeding can be defined as:

1. Plants with increased tolerance against stressors and improved intake and utilization of nutrients.
2. Plants with higher yields and higher content of valuable nutrients, lower content of undesirable substances and more efficient use of nutrients.
3. In 1996 the USA started with the global cultivation of GM soybeans. Presently, about 190 up to 200 million ha GM plants, such as soybeans, maize, cotton, rapeseed etc., are cultivated globally (Table 4). The highest portion of GMP is cultivated in states in South America e.g. Brazil, Paraguay, Argentina, Uruguay (Table 5).

Table 5: Cultivation of GMP in countries with the the highest portions (by FAOSTAT 2019)

Country	*GMP-Area (million ha)*	*Percentage of arable land (%)*	*Most cultivated plants*
USA	71.5	45.3	Soybean, Maize, Cotton, Rape seed, Sugar beet, Alfalfa, Papaya, Squash, Potato, Apple
Brazil	52.8	94.6	Soybean, Maize, Cotton, Sugar cane
Argentina	24.0	73.6	Soybean, Maize, Cotton, Alfalfa
Canada	12.5	32,4	Rape seed, Maize, Soybean, Sugar beet, Alfalfa, Potato
India	11.9	7.6	Cotton
Paraguay	4.1	87.2	Soybean, Maize, Cotton
China	3.2	2.7	Cotton, Papaya
South Africa	2.7	22.5	Maize, Soybean, Cotton
Pakistan	2.5	8.2	Cotton
Bolivia	1.4	31.1	Soybean
Uruguay	1.2	60.0	Soybean, Maize
Philippins	0.9	16.0	Maize
Australia	0.6	2.0	Cotton, Rapeseed, Safflower

By FAOSTAT (2019) cultivate further 42 countries <500 000 ha GMP

Europe is not mentioned in the present statistics (Table 5). GM-plants are only cultivated in the European countries Spain and Portugal (since 1998). About 1.65 million ha GM-maize has been cultivated up to now. The income of the farmers was 11.5% higher, if they cultivated gm-Maize. They used 37% less plant protection substances (Brookes 2019). Similar results have been reported by Qaim (2013) und Qaim and Kluemper (2014) as result of 147 studies with soybeans, maize, cotton and rapeseed. The production cost of cultivation of gm plants were 3% higher, those of use of pesticides were 38% lower. The plant yields were 21% higher and the production gain was 69% higher.

4. Safety Assessment and Feeding Studies

There exist many papers about safety assessment of genetically modified plants, such as EU (EU, 2003; EU, 2021, EuGH, 2018; Dederer, 2019; Purnhagen and Wesseler, 2020; EU 2021) In addition to many objectives of plant breeding, there are also some other results, such as lower content of mycotoxins (mainly Deoxynivalenol and Zearalenone) in maize. There exist also a lot of feeding studies to compare GM-Feed with non-GM-feed. At our Institute of Animal Nutrition at the Federal Research Institute of Agriculture (FAL; today Friedrich-Loeffler-Institute (FLI), Federal Research Institute for Animal Health), we carried out 20 feeding studies with various food producing animals (such as dairy- and beef cattle, fattening pigs, laying hens, broilers, laying quails). The results have been published in theses (e.g. Reuter, 2003; Tony, 2004), master studies and many publications (summary by Flachowsky 2013). A short review of studies with food producing animals is given in Table 6, summarized up to 2013.

Table 6: Published data about the using of feeds from gmP (Genetically modified Plants) of the 1st generation compared with the isogenic base lines (summary by Flachowsky 2013)

Animal Group	*Category*	*Number of Studies*	*Nutritional Assessment*
Ruminants			- No significant effects in composition (but lower content of mycotoxins in Bt-plants of feed. - No significant effects on digestibility of nutrients, animal health, yields of animals and composition/quality of food of animal origin.
	Dairy cows	23	
	Beef cattle	14	
	Further	10	
Pigs		21	
Poultry			
	Laying hens	11	
	Broilers	32	
Further animals			
	(Fishs, Rabbits etc.)	11	

In the meantime, there exist a lot of studies, which demonstrate the substantial equivalence of non-GM and GM food and feed (Flachowsky and Jany, 2022).

5. New Molecular Biological Techniques (Genome Editing; GE)

The Genome Editing (GE), also called "New Genomic Technique" (NGT), is one of the most important new developments. Scientists understand under "New Genomic Technique" clearly directed changes (mutations) of the nucleotide sequence of the genome of organisms. There are no new gene constructs in the plant, but only some DNA-constructs.

Therefore, genome edited plants are not gentechnique modified plants. They don't have genes of other plants in their organisms. For example, under CRISPR (***C****lustered* ***R****egularly* ***I****nterspaced* ***S****hort* ***P****alindromic* ***R****epeats*) and **Cas9** (***CRISPR*** ***a****ssociated* ***p****rotein*) do we understand a system, which is also available in various bacteria.

5.1. Objectives of Genome Editing

The objectives of Genome Editing are similar to GM-techniques. In the meantime, there exist a lot of plants, which are treated with NGT (Table 7). Some new techniques are summarized to new genomic techniques (NGT), for example, such as. Meganukleases, Zinkfingernukleases, TALEN, CRISPR/Cas9, Oligonucleotide Directed Mutageneses, Base Editing. All those techniques have the potential in short time to be successful. CRISPR-Cas9 is one of the most successful NGT without introduction of strange DNA. Tables 7 and 8 summarize some of the earleast examples of NGT on the base of German National Academies.

Table 7: Examples for plants which were successfully treated with New Genomic techniques (NGT; (EC 2021)

Group of plants	Which plants?
Cereals	Maize, Wheat, Rice, Barley, Milo (Sorghum)
Feed plants	Alfalfa, various grases, Setaria viridis
Fruits	Apple, Banana, Orange, Grapefruit, Kiwi, Melon, Stone fruits, Strawberry
Legumes	Beans, Peanuts, Peas, Chickpeas
Oil- and Fibre Plants	Soybeans, Rapeseed, Cotton, Flax, Sunflower, Mustard, Camelina
Sugar-Plants	Sugar beet, Sugar cane
Forest Tries	Poplar, Softwood-Treas (e.g. willows)
Tubers and Roots	Potatoes, Sweet potatoes, Manioc, Beetroot
Vegetables	Tomatoes, Broccoli, Cabbage, Pumpkin, Aubergine, Salats, Pepper, Chicoree
Further Plants	Cocoa, Coffee, Quinoa, Tobacco,

The objectives of NGT are similar to traditional plant breeding and GM-techniques (see the following list:

- Better used of ressources and higher plant yields
- Increase of tolerance/resistance against diseases and climate influences
- Higher content of some essential nutrients
- Reduction of content of undesirable substances in plants
- Increase of nutrient intake and more efficient use of nutrients
- Improve of steadiness of plants
- Improvement of content of plant ingredients
- Resistance against insects, virus, bacteria, fungi, herbicides etc.
- Salt Resistance
- Dry Resistance etc.

Many other authors agreed, that we need new ways for thinking and working in order to find new ways for food and feed production. Table 8 summarizes some examples of NGT in order to improve tolerance/resistance of feed and food plants.

Table 8: Examples of using of various genome editited techniques in plants

Plants/Culture	*Technique*	*Parameters*
Corn	CRISPR	Dry Resistance
Corn	CRISPR	Resistance against Leave diseases
Corn	EXZACT prec. technology	Herbicide resistance
Corn	CRISPR	Resistance against Maize Lethal Necrosis Disease
Wheat	TALEN	Mildew Resistance
Wheat	CRISPR	Dry Resistance
Rice	RTDS, ODM	Herbicide Resistance
Rice	RTDS, ODM	Resistances of various diseases
Rice	Cisgenese	Salt Tolerance
Rice	TALEN	Resistences against bacterial Diseases
Soybean	CRISPR	Dry- and salt tolerances
Soybean	EXZACTprec. Technology, ZNF	Abiotic Stress- and Herbicide tolerances
Soybean	CRISPR	Herbicide -/Dry tolerances
Soybean	TALEN	Dry tolerances, Herbicide resistances
Rapseed	TALEN	Herbicide resistances
Rapseed	Rapid Development System (RDS)	Herbicide resistances
Flax	TALEN, CRISPR, Rapid Trait Dev. System (RTDS);	Herbicide resistances

Plants/Culture	*Technique*	*Parameters*
Potato	Intragenese, RNA, Cisgenese	Resistances against cabbage and blight of the potato
Potato	TALEN	Better storage during coldness
Potato	RTDS, ODM	Resistences against cabbage and blight of the potato
Potato	RTDS, DOM	Herbicide resistances
Potato	Cisgenese, TALEN	Cabbage and blight of the potato
Potato	CRISPR/Cas	Cabbage and blight of the potato (*Phytophthora infestans*)
Tomato	CRISPR GE	Various Diseases
Apple	Cisgenese	Fire Resistance, Scab Resistance
Grape	Cisgenese	Resistance against fungi and seedlessness
Mushroom (Champignon)	CRISPR	Resistance against coloring

5.2. "Speed" of new Developments

There is a high speed of using NGT (Table 9) in plant breeding. The EU-SAGE (European Sustainable Agriculture Through Genome Editing; Dima *et al.* 2022) developed a new system of interactive data banc (https://www.eu-sage.eu/genome-search). In Table 9 you can see the jump in development of GE-plants during the last two years. Rice is absolut dominating in the number of genome edited plants, but most of the other plants were also used for NGT.

Table 9: Development of Genome Editing in various plants between 2020 and May 2022

Plants	*Modrzejewska et al. (2020)*	*Dima et al. (2022)*
Rice	81	171
Tomato	26	71
Corn	25	30
Soybeans	12	31
Wheat	14	26
Potato	14	21
Rapeseed	k.A.	24
Barley	k.A.	12

n.d.: no data

Altogether, 521 GE were registered up to April 2022. More than 50% were done in China (see below), mainly with rice:

Field studies with NGT-plants in 2022 (Dima *et al.* 2022):

1. China: 282

2. USA: 126
3. EU-27: 82
4. Japan.: 30
5. UK: 21
6. India: 13
7. Saudi-Arabia: 7
8. Pakistan: 7

In the EU, fundamental research is more or less dominating. Practical research is done in most of the other countries (see above). There are some advantages of NGT for plant breeding, such as improvement of yields, better and faster adaptation to climate change, more chances for small plant breeding companies etc. (Table 10).

Table 10: Potentials and Risks of Genome Editing for Plant Breeding on the bases of various Scientific Societies in Germany

Potentials/Chances	*Risks*
Lower costs compared to previous techniques; more chances for smaller companies	To fast introduction of new methods, Sufficient testing of new methods is necessary
Stable and higher yields under consideration of various conditions	Sufficient testing of new methods is necessary
Lower content of undesirable substances in Plants (such as toxins, phytate, further antinutriva etc.)	Sufficient testing of new methods under various conditions is necessary
Increased content of important nutritive substances (e.g. certain fatty acids, amino acids, minerals, vitamins etc)	Risk of overestimation of fast effects
Faster adaptation to climate changes	Sufficient testing of new methods is necessary

As mentioned above, Genetically Modified Plants of the first generation and Genome Edited Plants (NGT) did not have any significant influence on animal health and performance. Further studies in all fields of plant breeding and cultivation as well as human and animal nutrition are necessary. The potentials of NGT were demonstrated impressively by Dounda et al. (2022) recently.

6. Conclusions

Genetically modified (gmP) and/or Genome edited Plants (GeP) have the potential for higher yields, more and safe plant yields and reduction of production costs.

New developments should be observed and tested under field conditions in various countries in animals and men.

More details are given by Flachowsky and Jany (2022).

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