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Stakeholder questionnaire on new genomic techniques to contribute to a Commission study requested by the Council

Fields marked with * are mandatory.

Questionnaire on new genomic techniques to contribute to the study requested by the Council

Discussed and finalised in the Ad-hoc Stakeholder meeting on 10 February 2020

Background

The Council has requested [1] the Commission to submit, by 30 April 2021, "a study in light of the Court of Justice's judgment in Case C-528/16 regarding the status of novel genomic techniques under Union law" (*i.e.* Directive 2001/18/EC, Regulation (EC) 1829/2003, Regulation (EC) 1830/2003 and Directive 2009/41/EC).

To respond to this Council's request, the Commission is collecting contributions from the stakeholders through the questionnaire below. The study covers all new genomic techniques that have been developed after 2001.

Instructions

For the purpose of the study, the following definition for new genomic techniques (NGTs) is used: techniques that are capable of altering the genetic material of an organism and which have emerged or have been developed since 2001 [2].

Unless specified otherwise, the term "NGT-products" used in the questionnaire covers plants, animals, micro-organisms and derived food and feed products obtained by NGTs for agri-food, medicinal and industrial applications and for research.

Please substantiate your replies with explanations, data and source of information as well as with practical examples, whenever possible. If a reply to a specific question only applies to specific NGTs/organisms, please indicate this in the reply.

Please indicate which information should be treated as confidential in order to protect the commercial interests of a natural or legal person. Personal data, if any, will be protected pursuant to Regulation (EU) 2018/1725 [3].

[1] Council Decision (EU) 2019/1904, OJ L 293 14.11.2019, p. 103-104, https://eur-lex.europa.eu/eli/dec/2019/1904/oj
[2] Examples of techniques include: 1) Genome editing techniques such as CRISPR, TALEN, Zinc-finger nucleases, mega nucleases techniques, prime editing etc. These techniques can lead to mutagenesis and some of them also to cisgenesis, intragenesis or transgenesis. 2) Mutagenesis techniques such as oligonucleotide directed mutagenesis (ODM). 3) Epigenetic techniques such RdDM. Conversely, techniques already in use prior to 2001, such as Agrobacterium mediated techniques or gene gun, are not considered NGTs.
[3] Regulation (EU) 2018/1725 of the European Parliament and of the Council of 23 October 2018 on the protection of natural persons with regard to the processing of personal data by the Union institutions, bodies, offices and agencies and on the free movement of such data, and repealing Regulation (EC) No 45/2001 and Decision No 1247/2002/EC, OJ L 295, 21.11.2018, p. 39–98

Guidelines

Please note that the survey accepts a maximum of 5000 characters (with spaces) per reply field. You might be able to type more than 5000 characters, but then the text will not be accepted when you submit the questionnaire. You will also receive a warning message in red colour below the affected field.

You have the option to upload supporting documentation in the end of each section. You can upload multiple files, up to the size of 1 MB. However, note that any uploaded document cannot substitute your replies, which must still be given in a complete manner within the reply fields allocated for each question.

You can share the link from the invitation email with another colleague if you want to split the filling-out process or contribute from different locations; however, remember that all contributions feed into the same single questionnaire.

You can save the draft questionnaire and edit it before the final submission.

You can find additional information and help here: https://ec.europa.eu/eusurvey/home/helpparticipants

Participants have until 15 May 2020 (close of business) to submit the questionnaire via EUsurvey.

QUESTIONNAIRE

Please provide the full name and acronym of the EU-level association that you are representing, as well as your Transparency Registry number (if you are registered)

If the name of the association is not in English, please provide an English translation in a parenthesis

European Consortium for Organic Plant Breeding ECO-PB, Transparency Register: 329523333979-86

Please mention the sectors of activity/fields of interest of your association

Organic Plant Breding

If applicable, please indicate which member associations (national or EU-level), or individual companies /other entities have contributed to this questionnaire

If applicable, indicate if all the replies refer to a specific technique or a specific organism

it refers to crop plants

A - Implementation and enforcement of the GMO legislation with regard to new genomic techniques (NGTs)

* **1. Are your members developing, using, or planning to use NGTs/NGT-products?**

- ( ) Yes
- (x) No
- ( ) Not applicable

* Please explain why not

Organic plant breeders to not use genetic engineering techniques nor cell fusion or any technique with technical interferance below the cell level in their breeding process as this is not inline with the IFOAM International position https://www.ifoam.bio/sites/default/files/position_paper_v01_web_0.pdf and the definition of organic pant breeding of ECO-PB https://www.eco-pb.org/fileadmin/eco-pb/documents/discussion_paper/ecopb_PostitionPaperOrganicPlantBreeding.pdf.
For organic breeders the process is very important from the first cross till the final selection.
Dignity of creatures has to be taken into account. Like all living organisms, plants have an intrinsic value independent of human interests. Organic plant breeding promotes genetic diversity and takes into account the ability of natural reproduction. It also respects the genetic integrity of a plant, its crossing barriers and regulatory principles and is committed to safeguard the fertility, the autonomy and the evolutionary adaptation of our crop plants. This means that when varieties are chosen for organic farming, not only their suitability for cultivation but also their breeding history has to be considered. 1. The genome is respected as an indivisible entity and technical/physical invasion into the plant genome is refrained from (e.g. through transmission of isolated DNA, RNA, or proteins, or through artificial mutagenesis).
2. The cell is respected as an indivisible functional entity and technical/physical invasion into an isolated cell on growth media is refrained from (e.g. digestion of the cell wall, destruction of the cell nucleus through cytoplast fusions).
3. The ability of a variety to reproduce in species-specific manner has to be maintained and technologies that restrict the germination capacity of seed-propagated crops are refrained from (e.g. Terminator technology). 4. A variety must be usable for further crop improvement and seed propagation. This means that the breeders’ exemption and the farmers' right are legally granted and patenting is refrained from, and that the crossing ability is not restricted by technical means (e.g. by using male sterility without the possibility of restoration).
5. The creation of genetic diversity takes place within the plant specific crossing barriers through fusion of egg cell and pollen. Forced hybridization of somatic cells (e.g. through cell fusions) is refrained from.
Organic plant breeders consider NGTs as GMO as defined by the European Court of Justice in 2018 and therefore they are not allowed in in Organic breeding or orgnaic farming according the the EU Organic Regulation. Certain labell organisations also banned cell fusion (which is an older technique) and presently excempted from the EU GMO regulation.

*** 2. Have your members taken or planned to take measures to protect themselves from unintentional use of NGT-products?**

- (x) Yes
- ( ) No
- ( ) Not applicable

* Please provide details

As all breeders organic plant breeders rely on access of broad genetic diversity on different geographic regions. Organic plant breeders select the parental lines for the breeding very carefully in order to avoid contamination with GMO. To keep their breeding program free from GMO some organic breeders do not use seed from countries, for instance maize from the USA where GMO are widely used, they only exchange seed with well known and trustful partners, only use material developed before 1990 or invest quite a lot in GMO testing of potential parental material. Presently the release of GMO is restricted to few crops and detection methods, labelling and traceablilty systems are in place. However for the NGT there are no test systems available yet and labelling and traceability is not yet mandatory on international scale. Therefore tracing is very difficult. We also made the experience that mandatory declaration of GMO is very important but does not preventing GMO contamination which is detrimental to organic breeders. For the future of organic plant breeders is is vital to have access to a broad range of genetic diverse germplasmm which is free any contamination of GMO incl. NGTs. Moreover, organic breeders try to protect themselves by geograpic distance of GM-crops. However, this failed e.g. for maize in Spain. Today no organic breeding, seed production or maize cultivation is possible due to high contamination rate from surrounding GM-maize. In order to protect GM-free breeding and seed production from unintentional use of NGT-seed or their outcrossing, it is absolutely indispensable that the EU Commission, the EU Member States and their authorities ensure that the Directive 2001/18/EC is enforced for NGTs and NGT- products throughout the EU. Without such regulation, there is no mandatory labelling, traceability and information of cultivation sites which makes it impossible for organic breeders to safeguard their breeding material in the long term. The ruling of the European Court of Justice (C-528/16) that declared NGTs as GMO must be respected. Moreover it is important that the GMO declaration for NGTs is also enforced to imported seed.

* 2 bis. Have you encountered any challenges?

- (x) Yes
- ( ) No

* Please provide details

Access to GM-free genetic diversity is already severely hampered for organig breeders due to broad contamination of GM for crops like maize, rapeseed oil, cotton, soybean. GMO free certificates are expensive and not always trustworthy. Therefore breeders have to invest in own testing. However, if nothing is declared it is difficult to know what exactly to test. Moreover, if a breeder obtains for example only 10 to 50 seed per accession from a international genebank, it is impossible to do testing of a represenative sample before sowing, as then you destroy the seed. Thus, testing need to be done twice on the seed before sowing and after harvest. If there was a contamination during flowering, you risk that all the breeding material is contimanated, so you can use decades of work in one single season due to on batch of contaminated seed. It is also difficult to avoid cross contamination of GM crops of third parries especially for outcrossing species where pollen can be distributed by wind or bees several km, but also for self pollinating species like cotton. According to the European Plant Protection Right each breeder is allowed to use released cultivars from other breeders to participate commonly on breeding gain. However, until now there is no transparency except for GMO which techniques have been applied. For example, farmers and organic breeders that want to fulfill he requirements of private labels like Demeter, Naturland, Bioland, Gäa, Bio Suisse that banned cell fusion derived cultivars, have huge challenge to know if such methods was used in released varieties. For some crops test have been developed that are now implemented. However, they still cause financial burden to the organic plant breeders. Therefore full transparency need to be enforced by the regulation for all NGT so that breeders as well as organic farmers have a choice to maintain their business.

*** 3. Are you aware of initiatives in your sector to develop, use, or of plans to use NGTs/NGT-products?**

- [ ] Yes
- [x] No
- [ ] Not applicable

*** 4. Do you know of any initiatives in your sector to guard against unintentional use of NGT-products?**

- [x] Yes
- [ ] No
- [ ] Not applicable

* Please provide details

> Presently the organic breeders rely on the traceability and mandatory labelling for GMO to avoid use of parental material derived from with older and NGTs. For old GM techniques traces of unintended contamination can be quantified via qPCR technique. Other options are waiver of seeds from crops and origin with high risk for contaminion, waiver of material of research groups that published on NGTs, geographic isolation of the organic nursery and avoidance of winter nurseries that are highly frequented by conventional breeding companies using GM crops incl. NGTs to avoid cross contimination. Presently we are not aware of detection methods in place that can quantify contamination of NGTs in seeds or plants. There is a register on plants derived from NGTs as well as a register on patented varieties, however this is not mandatroy and therefore not complete.

* 4 bis. Are you aware of any challenges encountered?

- [x] Yes
- [ ] No

* Please provide details

> High risk for organic plant breeders when using modern germplasm that they might be contaminated by NGTs, also risk of contamination of older varieties and gene bank accessions due to multiplication in same geographic regions of GM crops. The lack of detection methods for NGTs increases risk of fraut by wrong declaration. No harmonisation on international level. The EU commission must therefore enforce transparency of all products and seed imported to Europe. No willingness of breeding companies to disclose their breeding methods. High economic burder of organic plant breeders for implementing many measures to keep their breeding material free from GMO. This will become extremely challenging when NGTs derived varieties enter the European market for many crops and traits.

*** 5. Are your members taking specific measures to comply with the GMO legislation as regards organisms obtained by NGTs?**

Please also see question 8 specifically on labelling

- [ ] Yes
- [x] No
- [ ] Not applicable

* Please explain why not

> Organic plant breeders to not use genetic engineering or other NGTs in their breeding program.

* 5 bis. What challenges have you encountered?

However, organic plant breeders have to take all possible meassures to avoid GM contamination along the whole breeding and seed multiplication process according to the EU organic regulation. Special guidelines were developed for the organic sector to prevent hazards at critical control points for organic production and pressing. Several organic breeders have developed their own standard operational procedure for all received seed lots to prevent contamination of GMO to their best knowledge.

* **6. Has your organisation/your members been adequately supported by national and European authorities to conform to the legislation?**

( ) Yes
(•) No
( ) Not applicable

* What challenges have you encountered?

There is a bit lack of protection of organic breeders to stay GMO free by EUropean or national authorities. Co-existance studies have not included organic breeding and were based on the organic food and feed where contamination levels below 0.9% need no declaration. However, 0.9% contamination is not acceptable to organic breeders as this is sufficient to contaminate the whole breeding material. Organic breeders have to carry the full risk with no public support. It is important that traceability is mandatore for all seed and cultivars (of EU origin or imported) that allows to distinguise those that have used old GMO and/or NGT in the breeding process and which not. For the organic sector it is not sufficient if the final product is free of GM or NGTs but the process is important. this is confirmed by organic consumer studies that expect organic products to refrain from old and NGTs. For example, apples bred with introduction of early flowering gene of birch to speed up breeding, and later crossed out is not allowed in organic agriculture. To protect the organic sector and to ensrue that expectation of consumers are met, it is important that the European commision sticks to the process and product approach in the GMO regulation and does not take over the product-based system only.

* **7. Does your sector have experience or knowledge on traceability strategies, which could be used for tracing NGT-products?**

( ) Yes
(•) No
( ) Not applicable

* Do you have suggestions on possible traceability strategies and/or methods?

(•) Yes
( ) No

* Please describe

Traceablility through process certification like the organic certification. Even if one cannot hardly prove by analytic methods that he an apple in the shop is organic, it can be certified organic and distinguished from non-organic products by process certification, full transparency and traceablility along the value chain which inspection and monitoring of the actors.
Secondly, the traceablility of applied breeding methods can be inforced by change of the EU regulation on plant variety protection. It should be manadatory of the release of each variety to disclose applied breeding techniques to national or Eurpean authorities (e.g. CPVO) like they also need to disclose the inbred lines used for hybrid variety production. This information need to be stored in the EU variety database and on request organic farmers or breeders can get information via the national authorities about those varieties that are complient with the organic EU regulation and values of national organic association.
Establishent of an International database were all NGTs are listed on a mandatory basis as well as related patents on it. As this is also for conventional breeders a burder to find out which varieties can be used for own breeding and which not due to patent protection.
It is important that it is enforced by European law that before release or import of NGTs detailed information is provided and that analytic tests to detect and quantify are developed to detect potential fraud or NGTs contamination. The costs for such tests should be covered by the organisations releasing such NGTs, by users of NGTs or by national or European funding. These imense cost can no longer be taken over by the organic sector, who is not profiting from NGTs.

*** 8. Are your members taking specific measures for NGT-products to ensure the compliance with the labelling requirements of the GMO legislation?**

- ○ Yes
- ● No
- ○ Not applicable

* Please explain why not

organic breeders do not apply NGT

* 8 bis. What challenges have you encountered?

There is great diversity how NGTs are regulated in individual countries outside the EU. Organic breeders have no information if there is no mandatory labelling and traceability system. It is also unclear which material from research projects end up in cultivars. Many new breeding techniques are developed like mutation breeding via retrotransposon activation that are not yet regulated and did not undergo safety accessment or regulation sofar, although this method is interfering in gene regulation on random sited of the genome www.epibreed.com. Therefore organic breeders have to keep alert on all new developments in breeding and find solutions how to avoid them. This does not only take a lot of time and financial resources but also dramatically restricts the access of GMO-free genetic germplasm. There are also not sufficient care taken to prevent genetic resources and landraces and wild crop relatives from contamination with NGTs. It is also frightening that NGTs can be created with limited financial resources by hobby researchers which will be hard to control and will further endanger the GMO-free resources. Strict regulation, manadatory labelling and regulary monitoring on presence of NGTs based on quantitative test systems is essential to keep control of the genetic resources and allow the growth of the organic sector in Europe and freedom of choice for breeders, farmers and consumers. This must be politically enforced throughout Europe and EFTA countries but also on international level.

*

9. Do you have other experience or knowledge that you can share on the application of the GMO legislation, including experimental releases (such as field trials or clinical trials), concerning NGTs/NGT-products ?

- ○ Yes
- ● No
- ○ Not applicable

Please upload any supporting documentation for this section here. For each document, please indicate which question it is complementing

The maximum file size is 1 MB

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B - Information on research on NGTs/NGT-products

* **10. Are your members carrying out NGT-related research in your sector?**

- ○ Yes
- ● No
- ○ Not applicable

* Please explain why not

Organic plant breeders to no apply NGTs as it is not compliant with the organic principles and therefore not involved in such research. In contrast organic plant breeders are aiming for more holistic approaches at the interaction of the plant with the living soil and breeding for plants that attract balanced microorganism communities following the holobiont approach (https://orgprints.org/36920/) or breeding for mixed cropping www.remix-intercrops.eu

* **11. Are you aware of other NGT-related research in your sector?**

- ● Yes
- ○ No
- ○ Not applicable

* Please specify

there is a lot of basis research in model and crop plants and applied research public and private conventional breeding sector.

* **12. Has there been any immediate impact on NGT-related research in your sector following the Court of Justice of the EU ruling on mutagenesis?**

Court of Justice ruling: Case C-528/16 http://curia.europa.eu/juris/documents.jsf?num=C-528/16

- ○ Yes
- ● No
- ○ Not applicable

* Please explain why not

The decision of ECJ provided a greater security of organic plant breeders and eased collaboration with conventional researchers on non-NGTs plant breeding as an alternative strategy

*** 13. Could NGT-related research bring benefits/opportunities to your sector/field of interest?**

- Yes
- (selected) No
- Not applicable

* Please explain why not

We are afraid that NGTs especially gene editing will concentrate on few traits (herbizide resistance, quality traits to ease industrial processing, and a few monogenic resistance genes) as you need to know the sequence to apply the NGTs. However, drought tolerance, nutrient use efficiency, yield stability or reseliance against a range of pest and diseases are based on many genes. Here genomic selection applying molecular markers will be much more promising and successfully applied in bigger breeding companies. Moreover, we are afraid that the NGTs will be used to improve individual genes of only one or two cultivars which are well established in the market like fireblight in the apple Gala. This will cause a shift in financial resources and breeding focus resulting in neglect of cross breeding and thus strong reduction of genetic diversity in the field. This will be especially true for vegetative propagated crops with long breeding cycles like fruits, grapes but also potato. For example in 1960 the banana cultivation was under global thread due to a fusarium race (Panama disease) as most of the cultivated banana belonged to Gros Michel. Then a resistant banana type Cavendish was found and instead of diversifying the genetic base, we still cultivate Cavendish on a global scale. As expected the resistance in overcome by the pathogen and today the only solution is sought in gene edition Cavendish. But then we might face another thread of new pest of disease. It also need to be considered that the plant genome exists of 20'000 genes and many replicated sequences involved in gene regulation. Even if we can modify 100 genes simultaneously by NGTs a breeder needs to balance the remaining 20'000 genes. Moreover we need to consider the plant - environment interaction, but also plant - soil interface. Therefore organic breeding is focusing on an alternative more systemic approaches. https://link.springer.com/article/10.1007%2Fs13593-018-0522-6

*** 14. Is NGT-related research facing challenges in your sector/field of interest?**

- (selected) Yes
- No
- Not applicable

* Please provide concrete examples/data

The NGT related research is using a lot of resources and public funding although societal acceptance by consumers are not yet given in Europe. This money is missing for other more holistic research approaches like breeding for organic and agroecological farmings systems like in the Horizon 2020 projects LIVESEED, DIVERSIFOOD, ReMIX, ECOBREED, BRESOV. Universtiy lectures on quantitative genetics, population genetics and practical plant breeding get more and more replaced by molecular biologists focusing on individual genes. Also training in practical crop specific breeding techniques obtains less attention. Research projects without application of NGT have a great challenge to get public reserach funding. Also researcher involved in field trials, participatory breeding approaches or systems-based approache have difficulty to get accepted in high ranking journals. https://www.sciencedirect.com/science/article/pii/S0048733309000614

*** 15. Have you identified any NGT-related research needs/gaps?**

- (•) Yes
- ( ) No
- ( ) Not applicable

* Please specify which needs/gaps, explain the reasoning and how these needs/gaps could be addressed

> There are not sufficient efforts (or interests) to explore and establish reliable testing systems to monitor NGTs. There is also a lack of research to explore acceptance of NGTs derived products and their willingness to buy such products and citizen involvement to steer the research agenda of public funded research. More research is needed on the impact of NGT on access to genetic resources, patents and Plant variety protetion and restriction of breeders' previlage to utilize released varieties for his own breeding.

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C - Information on potential opportunities and benefits of NGTs/NGT-products

*** 16. Could NGTs/NGT-products bring benefits/opportunities to your sector/field of interest?**

- ( ) Yes
- (•) No

* Please explain why not

> As organic breeding refrains from NGTs there is no immediate benefit visible for the organic sector in the near future.

*** 17. Could NGTs/NGT-products bring benefits/opportunities to society in general such as for the environment, human, animal and plant health, consumers, animal welfare, as well as social and economic benefits?**

- ( ) Yes
- (•) No

* Please explain why not

> The importance and urgent need of NGTs to feed the world in a sustainable way is overestimated. As mentioned before most imporant traits are the result of the synergistic action of many genes. Therefore NGTs might contribute but not solve the problems. Breeding must be conducted in a more holistic way integrating differnt disciplines, but also citizen participation and focusing on the UN Sustainability Developmental Goals. Besides breeding other interventions like change towards more plant based diets, reduced food waste, reduction of green house gas emisions, allocation and access to land, seed, water, eduction and decision power are fundamental for global change towards sustainablilty.

*** 18. Do you see particular opportunities for SMEs/small scale operators to access markets with their NGTs/NGT-products?**

- ○ Yes
- ◉ No

* Please explain why not

As organic breeders do not use NGTs, there is no market opportunity.

*** 19. Do you see benefits/opportunities from patenting or accessing patented NGTs/NGT-products?**

- ○ Yes
- ◉ No

* Please explain why not

The exchange of plant genetic material is essential for plant breeding. Farmers constantly need new varieties, as growing conditions on the fields and market demands change rapidly. Climate change makes it even more urgent for farmers to have access to a wide range of adapted varieties. Patents on seeds hinder the development of new varieties as they limit the access to genetic material to other breeders that is essential for innovation in breeding. Therefore, seeds and genetic traits that can be found in nature (regardless the technique used, including NGT) or obtained through conventional breeding must not be subject to patenting, also in order to protect farmers from intellectual property rights claims regarding the plants and animals they save and breed on their farm. Therefore we are strongly against patenting living organisms.

Patents will profit mainly multinational companies, that exchange or trade their patents and can determine who has access to their released germplasm and to which price. NGT will increase the number of patents on plants worldwide and make plant germplasm more and more proprietary of 3 global players. Since the development of our crop plants is the result of thousands of years of farmers selection and hundred of years of small scale breeders, this strong protection by patents is contradictory to the common value and heritage and shared benefit for society. This strong consolidation of the seed sector is a big risk of loosing genetic agrobiodiversity. Therefore free exchange of seed among breeders and farmer breeders should be promoted and not restricted.

Please upload any supporting documentation for this section here. For each document, please indicate which question it is complementing

The maximum file size is 1 MB

D - Information on potential challenges and concerns on NGTs/NGT-products

*** 20. Could NGTs/NGT-products raise challenges/concerns for your sector/field of interest?**

- ◉ Yes
- ○ No

* Please describe and provide concrete examples/data

The organic sector is highly affected by the release of NGTs products as it has to garantee the freedom of GMO along the value chain. Contamination with old GMO or NGTs at any step from breeding, seed multiplication, cultivation, storage, processing, transport, and trading will cause withdrawel of the organic label and in worst case the loss of the organic certification of the organisation. The sector is highly threatened by the release of NGT products if there are no clear regulation and monitoring how to Euroean and national authorities will protect the organic value chain against contamination. Costs of maintaining NGT-freedom must be covered by those providing the products or using them. Without European Regulation on labelling, testing and monitoring such NGT products it will be impossible to keep up to the organic regulation and consumers expectation of GMO free organic products. Only the present regulation of NGT according to the EU GMO regulations allows traceablity in Europe. However, a great challenge is that the establishment of a quantitative testing system depends on the information of the specific change due to NGT prodived by the researcher or breeder. If there is no such testing system in place there is a high risk of non declaration or fraud. Moreover the requirement for declaration and separation is not implemented in international trade agreements.

For organic breeders the threat is even greater as they rely on internation exchange of germplasm to improve the genetic diversity of his breeding program. Already a small contamination of < 0.9% can ruin his whole breeding material. As he obtains many 100 to 1000 of breeding lines and cultivars he cannot afford to test all of them and he must relay on NGT-free certificates of internationally certified labs that can quantify NGT contamination at very low level (<0.01%). The costs of testing should be free of charge for the provider and recipient of the seed. It should also be ensured that NGT crops are only cultivated in clearly defined clusters to avoid contamination via outcrossing in the whole region. If the application of NGT cultivars in Europe is largely increasing we are risking the same situation as for organic maize in Spain, where the organic breeding and seed multiplication is not viable any longer due to severe GMO contamination.

* Are these challenges/concerns specific to NGTs/NGT-products?

- (•) Yes
- ( ) No

* Please explain

The challenges are specific to NGT and related products as plants are genetically modified. So there is not only the risk of physical contamination like mixing of organic and conventional products, or one time contamination like pesticide contamination from conventional farming in one site and one season, but the genetic contamination. If there is only a small contamination in the seed source, this could spread and accumulate undetected from one generation to the next generation. Even if the source of seed is tested with greatest caution, there is an additional risk of contamination via outcrossing which cannot be totally controlled. Several studies have shown that co-existence of organic and GMO farming is very costly and in small scale agriculture systems almost impossible. If the current GMO legislation would be weakened, NGT-products would not be traceable anymore in the environment and the value chain jeopardizing organic and GMO-free sector as well as for the freedom of choice for consumers.

Physical and genetic contamination is one of the greatest threats for organic breeders. Moreover, also genetic resources, crop wild relatives and progenitors becoming more and more contaminated and are no longer available for organic breeding or farming. This is experienced for example in organic cotton breeding in India with 95% GMO cotton of the total cotton area www.sgf-cotton.org.

* **21. Could NGTs/NGT-products raise challenges/concerns for society in general such as for the environment, human, animal and plant health, consumers, animal welfare, as well as social and economic challenges?**

- (•) Yes

No

* Please describe and provide concrete examples/data

NGT and NGT products raise ethical concerns in the society. The dignity of living organisms has to be taken into account. Like all living organisms, plants have an intrinsic value independent of human interests. The dignity of the creature has been guaranteed in the Federal Constitution of the Swiss Confederation since 1992. It needs societal discurs on the ethical values in order to define which applications of NTGs are accepted or not. This cannot be decided by researchers or breeding companies alone.
NGTs are very efficient and powerfull tools to change the genetic basis of plants animals and humans. Therefore not only the technique applied is relevant but also the intended use and species will be important for the evaluation of risks and benefits for environment, human, animal and plant health. This is even more true for the socio economic impact. Some changes like gene drive can even lead to the extinction of whole species population. Moreover, with each new tool and progress in research we realize that our existing models of phenotypic expression needs improvement. It is doubtful if we have sufficient knowledge to foresee all consequences of such changes. Patenting NGT derived products will have a negative impact on availably of plant and animal genetic resources.
Besides the benefit and risk assessment also sustainability criteria and benefit for society should be considered like proposed in Norway. http://www.bioteknologiradet.no/filarkiv/2019/01/Proposal-for-relaxation-of-GMO-regulations-with-annexes.pdf
For consumer it is important to guarantee the freedom of choice and transparency.

* Under which conditions do you consider this would be the case?

These are general concerns that need on one side discurs with society and on the other side case by case evaluation.

* Are these challenges/concerns specific to NGTs/products obtained by NGTs?

(x) Yes
No

* Please explain

They are specific to NGTs and NGT products as it concerns living organisms and permanent changes in their genetic structure with great consequences on their future evolution.

*** 22. Do you see particular challenges for SMEs/small scale operators to access markets with their NGTs/NGT-products?**

(x) Yes
No

* Please explain and provide concrete examples and data

SME breeding companies are in a difficult position to compete with the market power of those few operators that control a major part of the market. Small operators are severely restricted by patents on plants and patents on NGT-technology itself, like Crispr/Cas. Patents are a major obstacle for small-and medium-sized breeding companies to develop plants and bring them to market independently. The necessity to negotiate patent-contracts with large corporations puts small- and medium sized breeding companies in a difficult situation, and license fees are a financial burden. Therefore, products that are developed by SMEs are consequently sold often to large scale operators to exploit the product commercially, which inhibits the emergence of SMEs on the market.

*** 23. Do you see challenges/concerns from patenting or accessing patented NGTs/NGT-products?**

- (x) Yes
- ( ) No

* Please describe and provide concrete examples/data

Patents on seeds hinder the development of new varieties as they limit the access to genetic material to other breeders that is essential for innovation in breeding. Therefore, seeds and genetic traits that can be found in nature (regardless the technique used, including NGT) or obtained through conventional breeding must not be subject to patenting, also in order to protect farmers from intellectual property rights claims regarding the plants and animals they save and breed on their farm. Therefore we are strongly against patenting living organisms.
Patents will profit mainly multinational companies, that exchange or trade their patents and can determine who has access to their released germplasm and to which price. NGT will increase the number of patents on plants worldwide and make plant germplasm more and more proprietary of 3 global players. Since the development of our crop plants is the result of thousands of years of farmers selection and hundred of years of small scale breeders, this strong protection by patents is contradictory to the common value and heritage and shared benefit for society. This strong consolidation of the seed sector is a big risk of loosing genetic agrobiodiversity. Therefore free exchange of seed among breeders and farmer breeders should be promoted and not restricted.

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E - Safety of NGTs/NGT-products

*** 24. What is your view on the safety of NGTs/NGT-products? Please substantiate your reply**

The risk of NGTs and NGT products depends very much on the plant species (outcrossing or not), their crop wild relatives, the region and total areal of release, the traits that are changed and the concrete technique used. For example producing novel drugs or vaccines or products for industry that does not occur in that species can have severe impact on nature wildlife and human health due to unintended outcrossing to food crops, like Eruca rapeseed oil and eruca free rapeseed oil. If plants are modified that are produced in closed containment in a climate chamber risk of outcrossing is much lower than for example for maize which pollen can be transported by wind many km. There are also big differences between the NGTs and the methodology how the genetic engineering is performed. Many methods involve protopast techniques were isolated cells without cell wall are exposted to NGT and need to be restored to a full plant afterwards. In certain cases gene editing is implemented by particle bombardment while other methods allow the gene editing via plant organs or whole plants put in certain solution to uptake components of CRISPR-Cas which can resample within the plant. Also some genetic changes are only transient others are permanent. Gene editing of type I concerns only small base pair changes that can also occur by random mutation, while with type II new mutations can be introduced that do not exist in nature, and in type III a cascade of different genes from differnt species with modified promoters can be introduced. CRISPR-Cas linked with genedrive overcomes Mendian inheritance and can erase whole populations as discussed for the elimination of anopheles fly to erase malaria. Same is possible for plants if there seed development is interrupted. I don't think that anyone can presently estimate what effect the loss of a specific species has in the entire ecosystem of the globe. But we are realizing the the unintentional loss of genetic diversity is endangering our future. Some of the NGTs influence not only the DNA sequence but the gene regulation like gene silencing (RNAi or methylation of genes), gene activation, activation of repressed retrotransposons. As we are only at the beginning to understand gene regulation and the different feedback loops between different genes, here risks of unexpected results are much higher than for a single base pair change. With each generation of NGT we learn that plant organism are much more complex than we thought. The ecological risk depends on the area where a trait is experessed. It makes a difference if for example Bt is sprayed based on pest indicence in a specific crop or if Bt genes are introduced in many crops grown on huge areas of the globe, causing resistance. Same holds true for round up ready GMOs. Therefore also unsustainable application is also a risk.

*** 25. Do you have specific safety considerations on NGTs/NGT-products?**

- (selected) Yes
- No

* Please explain

Reliable estimation of risk of NGT and their products is restricted by our limited knowledge on living organisms and their impact on the ecosystem including human health. Thinking that plant breeding works like putting desired genes together like a modular system when constructing a car is ignoring the fact, that development and reproduction of organisms, their reaction to environmental conditions, epigenetic imprinting and their evolution is much more complex and still not completely understood. Therefore safety assessment and monitoring of target and non target species in respective environment are important.

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F - Ethical aspects of NGTs/NGT-products

*** 26. What is your view on ethical aspects related to NGTs/NGT-products? Please substantiate your reply**

Cultivated plants are the basis for our food. For thousands of years, plant breeding has been intrinsically tied to our culture. It is therefore of vital importance for our future that farmers have access to seeds and vegetative propagation material of a wide range of locally adapted crop species and varieties. They should be allowed to adapt and improve them (crop species and varieties) by cultivation in their local and on farm conditions. Genetic diversity within and between species allows plants to adapt to changing environmental conditions, and it enables us to improve our crops through breeding according to our needs.
Hereby the dignity of creatures has to be taken into account. Like all living organisms, plants have an intrinsic value independent of human interests. Organic plant breeding promotes genetic diversity and takes into account the ability of natural reproduction. It also respects the genetic integrity of a plant, its crossing barriers and regulatory principles and is committed to safeguard the fertility, the autonomy and the evolutionary adaptation of our crop plants. This means that when varieties are chosen for organic farming,

not only their suitability for cultivation but also their breeding history has to be considered.

Ethical Criteria
1. The genome is respected as an indivisible entity and technical/physical invasion into the plant genome is refrained from (e.g . through transmission of isolated DNA, RNA, or proteins, or through artificial mutagenesis).
2. The cell is respected as an indivisible functional entity and technical/physical invasion into an isolated cell on growth media is refrained from (e.g. digestion of the cell wall, destruction of the cell nucleus through cytoplast fusions).
3. The ability of a variety to reproduce in species-specific manner has to be maintained and technologies that restrict the germination capacity of seed-propagated crops are refrained from (e.g. Terminator technology).
4. A variety must be usable for further crop improvement and seed propagation. This means that the breeders' exemption and the farmers' right are legally granted and patenting is refrained from, and that the crossing ability is not restricted by technical means (e.g. by using male sterility without the possibility of restoration).
5. The creation of genetic diversity takes place within the plant specific crossing barriers through fusion of egg cell and pollen. Forced hybridization of somatic cells (e.g. through cell fusions) is refrained from.
6. In complementation to the presently widely used hybrids, non-hybrid varieties shall be bred in order to give farmers the choice to produce their own seeds (farmers' privilege).
7. The principles of organic farming (the principles of health, ecology, justice and care) form the guidelines for breeding activities.

Criteria concerning breeding strategies
8. The environment in which selection takes place is in accordance with organic cultivation methods in order to account for the plant-environment interaction, to accelerate the selection gain, and to benefit from possible epigenetic effects. This means, that selection takes place under organic farming conditions.
9. The phenotypic selection in the field can be supplemented by additional selection methods (e.g. analysis of natural compounds or molecular markers for diagnostic purposes).
10. Organic plant breeders shall develop organic varieties only on the basis of genetic material that has not been contaminated by products of genetic engineering.

Socio-economic criteria
11. The exchange of genetic resources is encouraged and any patenting of living organisms, their metabolites, gene sequences or breeding processes are refrained from.
12. The breeding process, the starting material (e.g. used crossing parents, starting populations), and the applied breeding techniques will be disclosed to enable producers and consumers to choose varieties according to their values (e.g. clear declaration of varieties derived from mutation breeding).
13. Participatory breeding programmes involving all stakeholders (producers, processors, retailers and consumers) are promoted.
14. A plurality of independent breeding programs and breeders with different types of crops to increase agricultural biodiversity is aspired.

https://www.eco-pb.org/fileadmin/eco-pb/documents/discussion_paper/ecopb_PostitionPaperOrganicPlantBreeding.pdf
https://www.mdpi.com/2071-1050/9/1/18
https://research.wur.nl/en/publications/towards-resilience-through-systems-based-plant-breeding-a-review

*** 27. Do you have specific ethical considerations on NGTs/NGT-products?**

- (•) Yes
- ( ) No

* Please explain

Organic plant breeders have a strong view on ethical aspects related to NGTs. Based on our values we respect the dignity and integrity of living organisam including plants and their intrinsic value. This is very different from the utilarizm where the value only depends on the use for humans. Although breeding is changing genetic constitution of plants, organic plant breeding respects the integrity of the cell as smallest entity that has all information and potential to develop to an adult plant and produce seed. Therefore, not everything that is technically possible shall be applied. One criteria defined by organic plant breeder is that no method that is technically interfering below the cell level is in line with the organic principles of health, ecology, fairness and care. Breeding is seen as a close interaction and dialog between human and plant considering biological boudaries of the plant as well as their crosstalk with the living micro- and macroorganisms in the soil. Breeding should steer the evolutionary process of the crop plants to fit the benefit of human usage but within given limits of reproduction. Human culture and crop plants showing a certain co-evolution and breedders have to safeguard this heritage.

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G - Consumers' right for information/freedom of choice

* **28. What is your view on the labelling of NGT-products? Please substantiate your reply**

Labelling of NGT and derive products in indispensibe for organic plant breeding. Without such labelling organic breeders can no longer live up to their principles and cannot guarantee the provision of NGT free seed expected by organic farmers and organic consumers. Mandatory labelling and traceabilty is also a strong request of consumers who are more and more concerned about the process where and how our food is produced. Labelling is issential for consumers to make an informed choice according to their values. Labelling must also be enforced for products and seed imported to the EU.

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H - Final question

* **29. Do you have other comments you would like to make?**

- ○ Yes
- ◉ No

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Review

Concepts and Strategies of Organic Plant Breeding in Light of Novel Breeding Techniques

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Abstract: In this paper, we describe the development of a set of guiding principles for the evaluation of breeding techniques by the organic sector over time. The worldwide standards of organic agriculture (OA) do not allow genetic engineering (GE) or any products derived from genetic engineering. The standards in OA are an expression of the underlying principles of health, ecology, fairness and care. The derived norms are process and not product oriented. As breeding is considered part of the process in agriculture, GE is not a neutral tool for the organic sector. The incompatibility between OA and GE is analyzed, including the "novel breeding techniques". Instead, alternative breeding approaches are pursued based on the norms and values of organic agriculture not only on the technical level but also on the social and organizational level by including other value chain players and consumers. The status and future perspectives of the alternative directions for organic breeding are described and discussed.

Keywords: organic farming; plant breeding; guiding principles; alternative techniques; future perspectives

1. Introduction

Pluriformity in society and agriculture are important. According to Bawden [1], a balance in paradigms is important for the development of sustainable innovations. Each paradigm implies its own view on technology development, its own presumed best solutions, but also its own weaknesses. More pluriformity means the possibility for more solution pathways to exist and for more solution pathways to develop. Paradigms have different related ways of thinking (thought styles) and underlying values [2], which can result in different breeding approaches and strategies [3]. Related to different ways of thinking (hierarchical, individualistic, and egalitarian) are also different risk perceptions and different ways of managing risk [4,5]. Consequently, different scientific disciplines use different methodologies and methods [6,7]. The challenges societies worldwide currently are facing with respect to food security and climate change are complex, and no blueprint is available to solve this complexity. Hisschemöller and Hoppe [8] pointed out how many societal issues lead to controversies and can be categorized as "messy" problems as it is not merely a matter of finding agreement on the technical knowledge to solve certain problems but also on the underlying values that differ among groups in societies.

Organic agriculture is a private sector with its own developed values and standards. The organic sector is continuously developing and improving its farming and processing methods and where appropriate will adopt new strategies when they comply with the norms and standards. Specifically in the field of breeding there are different perceptions in societies on the suitability of modern breeding techniques such as genetic engineering (GE), especially for organic agriculture [9–12]. The controversies around whether or not the organic sector should adopt certain modern breeding techniques can be considered such a "messy" problem as there are not only technical aspects but also different opinions on values at stake. In this paper, we depart from the notion that there are different opinions on how to solve a problem, and that it should be possible to respect and maintain pluriformity in solution pathways in societies.

Organic agriculture (OA) is defined by the worldwide umbrella organization International Federation of Organic Agriculture Movements (IFOAM) as a production system that sustains the health of soils, ecosystems and people, by relying on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of non-organic, chemical-synthetic inputs. OA also promotes fair relationships in the value chain, reflected in IFOAM's four basic principles of Health, Ecology, Fairness and Care [13]. IFOAM defines "sustainable" as meeting the needs of the present without compromising the ability of future generations to meet their own needs, conserving an ecological balance by avoiding depletion or destruction of natural resources [14].

OA is a rapidly growing sector worldwide. A total of 43.7 million hectares were organically managed by 2.3 million organic producers at the end of 2014 which is approximately 1% of the worldwide agricultural land [15]. The global sales of organic food and drink reached 80 billion US dollars in 2014 [15]. With 11.6 million hectares, Europe covers 27.6% of the world's organic farmland with the largest areas in Spain, Italy, France and Germany. This area almost doubled since 2004. The European market for organic products in 2014 was valued €26.2 billion with a growth rate of 8%. European countries have top rankings for market share and per capita consumption worldwide [15]. For many countries the market demand is growing faster than domestic production. In a recent published vision of IFOAM called "Organic 3.0" it was estimated that the organic sector could potentially grow up to 20% worldwide of the total agricultural area [14].

For many years, the organic sector was considered the frontrunner of sustainable agriculture and the spin-off it had to the development of sustainability in conventional agriculture was the reason at the beginning of 2000 for many European governments to invest in OA. To maintain that leadership position of the organic sector, IFOAM calls for a continuous improvement in the sector towards more and more implementing best practices to develop "truly sustainable food and farming systems" [14]. This implies an integrated approach to make organic food and farming systems not only ecologically sound, but also economically viable, socially and culturally diverse and transparently accountable.

Organic farming systems produce on average lower yields compared with conventional agriculture. However, they are more profitable and environmentally friendly, and deliver equally or more nutritious fruits and vegetables [16,17] that contain less to no chemical-synthetic pesticide residues, compared with conventional farming [18]. The future challenge is to further optimize the productivity of organic farming systems to overcome the often discussed average yield gap of approximately 20% between conventional and organic agriculture [19–21] without compromising on long term sustainability [22]. However, other authors [20,23] discuss that the 20% yield gap does not count for all crops and all regions, as in some cases there is no difference or even an opposite trend towards higher yields for organic crops (e.g., barley, wheat and hay crops). One cause of the yield gap is the fact that organic farmers often apply 50%–80% of nitrogen through organic fertilizers compared to the amount of nitrogen in conventional farming systems, e.g., [24,25]. While the nitrogen of organic fertilizer will be slowly released it also prevents nitrate leakage to surface and ground water. In addition, the limited nitrogen supply also reduces too luxurious growth that could enhance pests (e.g., aphids) and foliar diseases (e.g., mildew) as in cereal production [25]. Another factor of limited yield under OA is the lack of cultivars adapted to low-input growing conditions without the use of herbicides, pesticides and fungicides. At present, around 95% of organic production in modern societies is based on crop varieties that were bred for the conventional high-input sector where mineral nitrogen fertilization and chemical-synthetic pest, disease and weed control are not a limiting factor [26]. The fact that such varieties are used in organic farming systems does not mean that they are optimally adapted, as often important traits required under organic and low-input production conditions are still lacking [26]. Organic farmers loose potential yield due to lack of sufficient weed suppression, pest and disease resistance traits in cultivars, such as against downey mildew in onion, late blight in potato and scab in apple [25]. Various pre-breeding programs to enhance such resistances are running and first resistant cultivars are being released [27,28].

All varieties of which seeds or propagation material have been propagated under organic growing conditions are currently allowed in organic agriculture, provided they are not declared as genetically modified varieties [29]. According to a derogation rule, untreated, non-organically propagated varieties are only permitted, if no suitable varieties from organic propagation are available. Among the currently available varieties the following categories can be distinguished [30]:

(1) Varieties derived from conventional plant breeding that are suitable for organic farming with the exception of genetically modified varieties (conventional breeding, organically propagated, or, if necessary, derogations are made for conventionally propagated but post-harvest untreated seed).
(2) Varieties derived from plant breeding programs with a special focus on the breeding goals or selection environments for organic farming, and organic seed propagation (product-oriented breeding for organic farming, organically propagated).
(3) Varieties derived from organic breeding programs or organic on farm breeding, which have been bred under organic farming conditions considering to the above mentioned criteria (process-oriented organic plant breeding, organically bred and propagated).

An essential element of organic farming is that it looks at agriculture as process based on a complex intertwining of agro-ecological, socio-economic and ethical principles. In addition, organic farmers are certified based on their farming process. Hence, organic farming looks at the breeding of new varieties in a holistic way. Thus, not only the variety characteristics itself but also the process of varietal development must comply with the guiding principles of organic agriculture. In this paper, we will analyze how the values of the organic sector have played a role in developing evaluation criteria and deciding what plant breeding strategies and techniques suit best for the further development of varieties that are adapted to organic farming systems. This will include the discussion on the so-called novel breeding techniques (NBT), sometimes also referred to as new plant breeding techniques (NPBT) [31], and we will discuss future requirements and challenges of organic breeding to meet the needs of this sector.

2. The Values and Regulation Setting of Organic Agriculture

In 1978 IFOAM was founded as the worldwide federation of organic agriculture movements, nowadays called IFOAM—Organics International, to unite all different organic agricultural initiatives and to find common ground in the norms and standards. In the 1990s, more and more conventional farmers converted to organic agriculture not only because of the organic values and societal pressure to reduce environmental risks but also as there was a growing market on local and global scale for organically produced and processed food [32]. That development finds its recognition in the forming of public regulation for organic agriculture on the European level and in addition public and private labels on national level mostly following the norms and standards that results from the organic values set by IFOAM. Other parts of the world, e.g., USA, Japan, etc., also followed with public regulations for organic agriculture [15].

Values are the result of a complex interplay of culture, politics, the market and the agro-ecological conditions. Values give arguments to: (i) explain the current status; (ii) give guidance to desired new developments and exclude undesired developments; (iii) pro-actively set up research and development; and (iv) evaluate and adjust standards for organic agriculture. As norms and standards are bound to time and culture, they need to be updated from time to time. Therefore, IFOAM organized a worldwide democratic process among members (close to 800 affiliates in 117 countries) over a period of two years which resulted in 2005 in reformulated values expressed in four basic principles: the principles of health, ecology, fairness and care [33]. The principle of health refers to supporting the wholeness and integrity of living systems (immunity, resilience, regeneration, sustainability), while the principle of ecology refers to the need to contribute to optimally functioning of a diversity of site specific ecological production systems and refraining from chemical-synthetic substances. The principle of fairness refers to social aspects and stresses the importance of serving equity, respect, justice and stewardship of the shared world, whereas the principle of care enhances efficiency and productivity of organic farming and processing in a precautionary and responsible manner.

2.1. The Arguments of the Organic Sector's Ban on Genetic Engineering

As the organic certification is based on the farming process rather than on the end products as such, it implies that also breeding as an activity within the agricultural process and is evaluated for compliance to organic values and rules [34]. The first ban on GE came from IFOAM's General Assembly in 1993 [35], followed by the European Regulation for organic agriculture in 1999 [29]. The main arguments given at that time by IFOAM were mainly related to ecological risks but also included a first notion of ethical arguments based on respect for the integrity of life, including plants [35]. The conceptualization of this argument of integrity of life was elaborated some years later [36], and further discussed in Section 2.2. Verhoog [37] further analyzed the arguments of the organic sector and summarized them in three categories: (i) environmental and health risks; (ii) socio-economic and legal aspects; and (iii) values and principles of sustainability of the organic sector.

With respect to the first category of arguments concerning environmental and health risks, the organic sector feared the unpredictability of undesired side effects such as environmental and health risks considered from the organic holistic view as inherent to the reductionist approach of GM, supported by the fact that many scientists were not agreeing on the risk-analyses and the interpretation of those data [37]. While the risk of GMO plants might have been overestimated, their claimed benefit was also exaggerated [10]. The widespread use of herbicide resistant genotypes eased the workload of conventional farmers, however, it also resulted in increased herbicide residues in feed and human food [38] and within short time their benefits are overcome by resistant weeds. Similar for Bt cotton, after wide spread use, severe yield losses were caused in India in 2016 due to resistant pink bollworm attack [39]. Giving high priority to holistic approaches, the organic sector has a different risk perception and therefore different interpretation of outcomes of risk analyses. Hence, it rather applies the precautionary principle (Principle of care) to avoid any ecological risks and therefore seeks for alternative solutions.

With respect to the second set of arguments (socio-economic aspects), the organic sector was concerned about the freedom of choice for the farmer and consumer due to contamination of GE and non-GE products as not every country has clear coexistence rules [37]. Another aspect in this category is the concern about the intellectual properties rights through patenting and the loss of independence of farmers in their choice of seeds and their ability to save their own seeds.

The third category of arguments was related to the incompatibility of GE with the principles of sustainability of the organic sector based on the holistic approach to the living nature, respecting and supporting the ability of self-regulation by ecological management and respecting the integrity of living entities, based on the four basic principles of OA as described above [36,37].

2.2. Continuous Developments and the Need for Clear Evaluation Criteria

In the early stages (end of the 1990s) of the GE development, the Dutch government accepted the exclusion of GE by the organic sector but required the Louis Bolk Institute to develop a clear and consistent framework and criteria to evaluate all at that time existing breeding techniques. This resulted in a process with many national and international workshops with organic players and reports since 1997 [40–42]. The organic sector goes a step further than from a stewardship attitude that considers natural resources at the disposal of mankind albeit managed with care in order to maintain resources for next generations. From the holistic view the organic sector embraces the partner attitude towards nature which includes that not only humans and animals but all living entities, including plants, are considered ethically relevant out of respect for the integrity of life, referring not only to an extrinsic value (usefulness for mankind) but also to a perceived intrinsic value of living organisms (worth as an living entity as such based on respect for their "otherness", dignity, wholeness and autonomy). The dignity of living organism including plants have for example been implemented as a common value in the Swiss Federal Constitution of 2002 [43]. This respect for the integrity of life has consequences in the decision making on how to manage (cultivated) plants in OA, refraining from violating the integrity of life and as a consequence cooperating with nature rather than excluding nature [36]. This respect for the integrity of life is also one of the reasons for organic agriculture to refrain from inorganic (chemical-synthetic) substances and to allow only organic substances.

To make the concept of intrinsic value of plants operational, four levels of integrity have been distinguished: (i) the level of the nature of life in general; (ii) the level of the specific nature of plant life; (iii) the level of the species-specific nature of plants; and (iv) the level of the nature of individual plants [36]. Breeding techniques can be evaluated for violating one of more levels of integrity of life.

Techniques for variation induction, selection, maintenance and propagation can be applied at three levels: plant or crop; cell or tissue (in vitro), and DNA. As organic agriculture aims to work within the realm of life while respecting the integrity of life, the techniques that go beyond the whole plant level are considered not suitable with the values of organic agriculture and thus not suitable for use in organic plant breeding programs. As the cell can be technically considered as the lowest level of self-organizing life (as the plant can be regenerated from a single cell), one could argue that it could be allowed and it is not forbidden in the organic regulation and reflects the middle position between the two other more clearly defined categories. Techniques directly engineering at DNA level go beyond the level of the self-organized life and are therefore violating the integrity of life, and more specifically the genotypic integrity e.g., when it forces natural crossing barriers [36]. Similarly, cell fusion where cell DNA and cell cytoplasm from different organisms are merged by technological means are considered as GE according to IFOAM definition of GE in the IFOAM norms [44]. On the other hand, the use of molecular markers is not excluded in organic breeding as they are diagnostic tools for plants and do not directly interfere in DNA [45]. The organic approach is aimed at the quality of the process, respecting the integrity of living entities, therefore the focus is on a holistic approach at all organization levels, and not on an approach whereby the parts are dissected in order to guide processes on a lower organization level. This approach has been very helpful for the organic sector to determine what approaches are suitable, but sometimes criticized by scientists. The criticism is that if the organic sector wants to be completely consistent, it should also exclude all varieties bred with techniques (e.g., through mutation breeding) in the 1950 to 1980s that do not comply with the development of the IFOAM definitions [46].

With the advent of new breeding techniques and methodologies, it became clear, that the organic sector needs an agreement on transparent criteria for their evaluation. After various discussions on a national and European level the European Consortium of Organic Plant Breeding (ECO-PB), being one of the IFOAM member organizations, submitted in 2012 a position paper on the goals and values of organic plant breeding and defined various criteria for the assessment of new breeding techniques [41,42]. ECO-PB formulated the aims of organic plant breeding as follows: (1) The breeding goals shall match the respective crop species and the needs of the complete value chain of the organic sector (producers, processers, traders and consumers). The breeding goals shall aim at the sustainable use of natural resources and at the same time account for the dynamic equilibrium of the entire agro-ecosystem; (2) Organic plant breeding supports sustainable food security, food sovereignty, secure supply of plant products (e.g., fiber, medicine, timber), and the common welfare of society by satisfying nutritional and quality needs of animal and human beings; (3) Organic plant breeding sustains and improves the genetic diversity of our crops, and thus contributes to the promotion of agro-biodiversity; (4) Organic plant breeding makes an important contribution to the development of our crops and their adaptation to future growing conditions (e.g., climate change). The ethical criteria, criteria for breeding strategies and the socio-economic criteria are described in detail in the position paper of the European Consortium of Organic Plant Breeding (ECO-PB) [41]. The ethical criteria to respect the genome and the cell as indivisible functional entity follow the concept of respecting integrity of life, and which is also at the basis of the basic principles of OA as above described. Therefore any technical or physical invasion into the isolated cell is refrained from and plant specific crossing barriers are respected, irrespective of potential benefit risk assessments. An important point in the breeding strategy is that organic plant breeders—breeding exclusively for OA—perform all steps from crossing till selection and multiplication under organic growing conditions. On the socio economic aspects, ECO-PB is promoting free exchange of germplasm, transparency of the breeding process, open pollinated varieties instead of F1-hybrids, participatory breeding involving farmers and the value chain and a plurality of breeding initiatives to enable a more diverse and sustainable agriculture.

Organic plant breeding is a holistic approach where the process of breeding, including technical, socio-economic and ethical aspects, is equally important as the final product (cultivar) with its characteristics [47]. With new labels for organically bred varieties such as "Bioverita" in Switzerland the sector tries to communicate its values and create valorization along the value chain up to consumers (www.bioverita.org).

New sequencing approaches combined with an increase in identification of candidate genes and more precise techniques of genetic engineering will have a big impact on plant breeding, especially since the new methods like CRISPR-Cas9 are much easier and cheaper in their application than former methods [48–51]. The potential advantages of these new techniques have been widely published. However, there has been on ongoing debate in the European Union (EU) regarding how to handle novel breeding techniques like Zinc finger nucleases, oligonucleotide directed mutagenesis, cisgenesis and intragenesis, RNA-dependent DNA methylation, grafting on GM rootstock, reverse breeding, agro-infiltration and synthetic genomics with respect to commercialization of derived cultivars for several years. Until now no legally binding decision has been made by the EU if the individual techniques shall fall under present rules for genetically modified organism (GMO) legislation [52,53]. The main drivers for adopting such techniques are their technical potential and their economic advantage by speeding up breeding processes, whereas prerequisite of known genetic information and the uncertainty if final cultivars will be classified as GMO or non-GMO are hampering the utilization of these techniques [52]. In their recommendation, Lusser et al. [53] differentiated between those techniques that: (i) introduce whole genes or longer DNA fragments versus those with less than 20 base insertion; (ii) if these genes are from the same species or different species; (iii) if they are transient or stable integrated; and (iv) if the modified plant can be detected, i.e., if they can be clearly distinguished from plants derived from cross breeding or not. If only small DNA changes have been introduced (e.g., gene editing through oligonucleotide, zinc finger nucleases, TALEN or CRISPR-Cas9) or if the gene regulation is modified (e.g., RNA-dependent DNA methylation) it will not be possible to detect such changes, except if it is protected by a patent which requires traceability.

In addition, other countries such as the USA, Japan, and Australia are struggling with proper regulation. A notable difference between EU and USA regulation is that in the EU legislation on GE the process and the product of GE are considered, while in the USA only the final product is evaluated [49]. The US recently released the first products, an anti-browning mushroom and a waxy corn, genetically modified with the gene editing tool CRISPR-Cas9 for commercialization without the oversight of the US Department of Agriculture with the justification that these products do not contain genetic material from plant pests such as viruses or bacteria [54]. The general public's view on safety aspects of foods derived from products of new genetic engineering techniques and the process based approach in Europe are the greatest hurdle faced for definition and implementation of regulatory processes for new plant breeding technologies in Europe. Given the difficulty in conveying concepts of modern biotechnology to the general public, there is considerable potential that the public may not immediately embrace genome editing [55]. Therefore, several attempts are made to convince the organic sector about new technologies [46,56] in order to reach out to the consumers. New genome editing technologies/modern biotechnology techniques have the promise to make plant breeding more efficient and precise. They create specific mutations and have the potential to generate plants that differ from the original plant at a single nucleotide position and otherwise carry no signs of the modification [49,56,57]. Although these techniques are causing off-target mutations, the expectation is that in the future the number of off-target mutations is likely to reduce due to technological advances [49]. However, off-target mutations caused by gene editing need to be compared to a mutation rate of 3.3 base substitutions per generations in *Arabidopsis thaliana* [58].

It is clear that scientists are aware of public concerns [49,56,57,59]. However, opinions of scientists on increasing the acceptability of these technologies for the public vary. Some expect that over time GE will become accepted by the organic sector [56]. Others recognize that although new biotechnologies are becoming more precise and consumer disapproval gradually reduces, techniques such as cisgenesis still is considered as unnatural by those consumers [59]. It is expected that consumers of conventional products prefer more precise novel biotechnologies over transgenesis, and that this change in attitude is not the case for consumers of organic products [57]. Hence, it is important that scientists acknowledge the pluriformity in public opinions, and that a pluriformity in science and plant breeding is equally important. This also means that in scientific debate similar space should be available for criticism of the soundness of the arguments of the organic sector to determine acceptable principles for organic breeding [45] as for the arguments of the organic sector itself [36]. Based on the principles of organic plant breeding described by the ECO-PB [41] and in the IFOAM Norms for organic production and processing in 2014 [44] any breeding technique can be evaluated against these criteria (Table 1). The first five criteria are mandatory, whereas the possibility of farm saved seed is preferred but not an exclusive criterion. For example, marker assisted selection is a diagnostic tool based on the analysis of DNA. It does not interfere physically at the genome or cell level, it does not overcome species specific crossing barriers, and does not affect breeder's privilege or farmers' right to produce farm save seed; therefore this is acceptable for the majority of organic plant breeders. In contrast, methods which technically alter the DNA or RNA by methods of genetic engineering are not considered to be compatible with organic breeding, as this violates the integrity of the genome. Likewise, cytoplast fusion is not accepted as this is based on technically forced fusions of somatic cells to overcome species specific crossing barriers in order to introduce traits such as male sterility. This violates the integrity of the cell as a functional unit.

For the organic sector this debate is of great importance at two levels. First of all, the organic sector has to define in a participatory process including all stakeholders of the organic sector clear criteria for the evaluation of new techniques for organic plant breeding. Secondly, the organic sector has to decide which cultivars derived from conventional breeding programs are acceptable for organic production as they meet the IFOAM principles as well as the expectations of the consumers.

Table 1. Criteria for the evaluation of breeding techniques with the principles of organic plant breeding, as described by the European Consortium for Organic Plant Breeding (ECO-PB) [41] and International Federation for Organic Agriculture Movements (IFOAM) Norms of 2014 [44].

Breeding Technique	Interference on Genome Level	Interference on Cell Level	Ability of Propagation Is Affected	Overcoming Crossing Barriers	Breeder's Privilege Is Affected	Farmers Rights to Use Farm Saved Seed Is Affected	Tracing Possible
Marker assisted selection	No	No	No	No	No	No	No
Cytoplast fusion	No	Yes	Case specific	Yes	Partly	Yes	Yes
Zinkfinger Nucleases I and II	Yes	Yes	No	No	Yes (patent)	Yes (patent)	No
Zinkfinger Nuclease III	Yes	Yes	No	Possibly	Yes (patent)	Yes (patent)	Yes
Cisgenetics	Yes	Yes	No	No	Yes (patent)	Yes (patent)	Case specific
Transgenetics	Yes	Yes	Possibly	Yes	Yes (patent)	Yes (patent)	Yes
RNA Interference (RNAi)	Yes	Yes	No	No	Yes (patent)	Yes (patent)	No
Reverse breeding	Yes	Yes	No	No	Yes (patent)	Yes (patent)	No
Minichromosomes	Yes	Yes	No	Yes	Yes (patent)	Yes (patent)	Yes

With respect to the first task to evaluate the NBT, the organic plant breeders of ECO-PB share common values expressed in the position paper and they will not apply the above mentioned techniques in their breeding programs as in their understanding this violates the integrity of the genome or the cell. The second task to define which cultivars should be allowed in OA is much more difficult and presently under discussion at IFOAM International. Here the criteria might obtain a different priority. An example is cell fusion, which is not applied by organic plant breeders, but used widely to obtain male sterile plant for hybrid seed production in brassica vegetables. Some private labels in Germany have already banned cultivars based on cell fusion for OA, due to the fact that the integrity of life and more specifically the genotypic integrity is violated and species specific crossing borders are overcome. In order to have a well-informed discussion the different breeding methods have been described indicating their applications, potentials and ethical issues [42]. As the application of some of the novel genetic engineering techniques are not detectable, the organic sector is very concerned that they might be released without labeling. In that case, the organic sector will no longer have the freedom of informed choice. Therefore, there is a strong lobbying of IFOAM for disclosure of the breeding methods, which is presently only given if the techniques fall under the GE regulation. Transparency and freedom of choice for farmers and consumers as well as a plurality of breeding strategies will allow co-existence of GM and non-GM food chains, and will be beneficial to pluriform societies (e.g., [1–3]). Having experienced the impact of coexistence of GE on OA [60], and the disappearance of non-GE cotton seed in India within only 10 years [61], it is important to take measures in advance that different farming systems can co-exist.

In the USA, the National Organic Standards Board has decided to update the organic standards to exclude cultivars and derived organic products developed with new generation genetic engineering end gene editing techniques [62]. In Europe, a position paper of the IFOAM EU GROUP [63] urges that cultivars derived from NBT which engineer living organisms in the cell and/or nucleus through technical, chemical or biotechnological intervention shall be defined as GE and be subject to a risk assessment and if authorized for release be subject to the mandatory traceability and labeling requirements that apply to other GE techniques. This transparency is important to ensure organic farmers and customers free choice of non-GE seed and food, respectively. At the international level, the IFOAM has set up working groups on the definition of GE and the criteria for the evaluation of NBT to be discussed among the organic movement and IFOAM's members at the next general assembly in 2017.

3. Developing Alternative Breeding Concepts

What modern breeding techniques suit the organic sector? With the framework described in the above section it is possible to evaluate what breeding methods are appropriate and in which direction to search for good alternatives as a consequences of rejecting certain breeding techniques. The organic sector would set itself back when it does not challenge itself to seek for alternative innovations. The organic sector has dealt with such challenges before when it decided to refrain from chemical-synthetic pesticides and herbicides which implied learning how to enhance and manage biodiversity to build up agro-eco resilience and thus lowering the pest and disease pressure [25]. Refraining from synthetic fertilizer resulted in improved organic fertilizer management like composting to improve soil fertility. In the same sense, we can argue that refraining from GE is not a disadvantage but may stimulate efforts to develop innovative suitable approaches to breed for adaptive, flexible and nutritious varieties to combine plant robustness with food quality.

Does the critical evaluation of breeding techniques imply a completely new variety assortment? This is not the case; the degree of overlap between varieties suitable for conventional and/or organic farming systems depends on the crop requirements and the applied breeding techniques. In some specific crops, the problem to find suitable varieties that can perform well without high levels of mineral fertilizers and chemical-synthetic fungicides, herbicides and pesticides is larger than for other crops. For several crops like maize [64] and wheat [65] it has been shown that direct selection under the target farming system was essential to reach maximum breeding gains for low-input and organic farming. Cultivars for OA also need to have high weed competition or tolerance, high level of tolerance against soil and seed borne diseases and especially high requirements for shelf-life, as synthetic conservatives are not allowed. There is not only a need for varieties that fit in an organic system with good yield potential and nutritional quality but also that allow the organic systems to work, meaning that the resilience of the whole farming system is supported and enhanced. Luby et al. [66] argue that the organic sector has not yet reached its full potential until growers have access to regional adapted and organically bred varieties that balance yield with nutritional quality. In addition, organic plant breeding aims to contribute to new more sustainable production systems through breeding for more diversity within cultivars, development of composite cross populations of cereals presently under test marketing in the EU, or breeding for mixed cropping systems and for improved resilience due to enhanced plant-microbe symbiosis.

3.1. Future Direction for Crop Improvement in Organic Agriculture

Values are not only aiming at excluding unwanted developments but also to give direction to desired developments in breeding. The IFOAM basic principles—the principles of health, ecology, fairness and care—are very helpful to support the development of appropriate breeding approaches [44]. Besides, breeding is not only a technical activity but also a socio-economic and legal construction. This requires creativity to find suitable organizational and business models to finance breeding for a diverse assortment adapted to various regions and various crops, including small crops. This is particularly reflected in the principles of fairness and care.

The Principle of Health in organic plant breeding is about serving the wholeness and integrity of living systems (including society) at various levels (immunity, resilience, regeneration, sustainability). The implication for breeding is that varieties need to be robust and dynamic, weed suppressive and disease tolerant, able to benefit from interactions with beneficial soil organisms, and to reproduce themselves and to produce high quality, nutritious food.

The Principle of Ecology in organic plant breeding is about contributing to optimally functioning of a diversity of site specific ecological production systems. This means that breeding needs to develop multilevel approaches, such as decentralized breeding for regional adaptability and enhancing genetic diversity and adapt the seed to the environment instead of the environment to the seed.

The Principle of Fairness in organic plant breeding is about serving equity, respect, justice and stewardship of the shared world. It implies the need to develop new socio-economic structures in breeding to ensure free access to genetic resources, no patents of life, breeding approaches that involve all value chain actors, equal benefit sharing among chain partners, and maintenance and accessibility of diversity for future generations.

The Principle of Care in organic plant breeding is about enhancing efficiency and productivity in a precautionary and responsible manner. We argue that there is plenty of unexplored (and forgotten) knowledge for new multifaceted breeding strategies! It means that organic breeding refrains from breeding techniques that interfere directly at DNA, including cell fusion and mutation breeding, and stimulates transparent and participatory/collaborative processes.

Varieties that meet these four criteria can be called organic varieties [67]. The question is how to organize and finance breeding for so-called organic varieties? The past 10–30 years various initiatives at various levels (e.g., farmers, breeders, researchers, and wholesalers), particularly in Europe [68] and North America [69], have been set up to develop approaches that fit organic breeding better. Next to the development of organic breeding companies in the past 30 years, we can identify two novel approaches including combinations of both.

- Chain-based breeding: The whole chain is involved, either contributing in cash, or in kind. For successful chain-based breeding, it is important that all chain players have economic benefit, directly, or indirectly. An example is the Dutch potato breeding system based on collaborations between commercial breeding companies and various potato growers involved in the early selection process [70].

- Community-based breeding: A group of people, together forming a community, sharing an idea or vision. For successful community-based breeding, it is important that the community has a clear common vision and goal. An example can be farmer-based breeding: a group of farmers working together (Kultursaat in Germany). A group of farmers and bakers can also form a community (Resources de Semence Paysanne in France).

3.2. How to Stimulate Organic Variety Development?

In order to make such initiatives successful and to meet the needs of a diversified organic market, it is important to take the local/regional agro-ecological and socio-economic context into account. A set of key-elements has been developed to understand how to increase the chances of success [67]. One important element is that policy makers can play an important role to increase the window of opportunity for such initiatives. At the moment many of these initiatives are set up at the niche level. Policy and law influence the possibility of such small initiatives to grow, although in different ways, as, for example policy and law on organic seeds in the EU and US are different [71]. Good interaction with market players that are part of the mainstream agriculture can increase the longevity of such initiatives or even influence and reshape conventional breeding and agriculture. According to Geels and Schot [72] there are various transition pathways. The success of these transitions depend on a number of factors: (1) entrepreneurial activities; (2) knowledge development; (3) knowledge exchange; (4) guidance of the search; (5) formation of markets; (6) mobilization of resources; and (7) counteracting resistance to change [73]. The past 30 years, particularly entrepreneurial activities, knowledge development, knowledge exchange and formation of markets have increased clearly. Counteracting resistance to change has reduced as the number of conventional seed companies selling organically produced seed continuous to grow. For example, in the Netherlands, 42 companies are producing organic seed [74]. As the organic sector is growing and organic seed production is growing at a fast rate, it is plausible breeding for organic and organic breeding gradually can become more profitable in the future. Some of the organic breeding initiatives such as the community-based initiative Bingenheimer Saatgut in Germany started at the niche level and is gradually becoming a normal market player.

3.3. Institutionalisation of Organic Plant Breeding

Successful innovations cannot always be planned [75,76]. Some innovations are the result of institutionalized processes, whereas other innovations emerge spontaneously [76]. Perhaps this needs to be considered an advantage: to increase genetic diversity and crop diversity, it is crucial to have diversity at the socio-economic level. The more different types of breeding initiatives develop, the more crop diversity will be maintained.

Beneficial institutionalizing processes of organic plant breeding are developing a clear set of standards. For example, IFOAM has adopted standards for organic seed production within their basic standards, and drafted standards for organic plant breeding in collaboration with ECO-PB [41]. Since 2004, the EU has stipulated in their regulation that OA requires organically produced seeds, and requires request for derogation for the use of non-organic seeds (see www.organicxseeds.com). However, institutionalization may mean increasing efficiency, but may result in decreasing diversity. Therefore, a careful balance between institutionalization and the spontaneous development of new initiatives need to be taken care of. At the moment some conventional companies (potato, vegetables, cereals and fodder crops) become more interested in the (conventional) sustainable or low-input and organic market sector, and see opportunities to serve both markets by slightly reshaping their breeding program [30,77].

There is also recognition at scientific level: In 2005 the first professor of organic plant breeding was appointed at Wageningen University, and in 2013 at Kassel University, and five planned in the

USA [78]. Research programs for organic plant breeding activities are running in many countries [47], and at the European level the Horizon 2020 program calls for projects on organic seed and breeding.

4. Discussion

In this paper, we have described the development of a set of guiding principles for the evaluation of breeding techniques by the organic sector over time. As there are differences in values between organic and conventional agriculture, we first described the basic principles of OA. Bringing such underlying values forward is a choice of the international organic movement represented by IFOAM and allows the organic movement to distinguish itself from other approaches in sustainability. Organic products serve consumers who share the values of OA. In that perspective, and given the self-chosen principles of OA, we will discuss the consequences of such choices for the future of organic seed and breeding.

It is often argued that in order to meet the food demand of a growing population, all available tools need to be applied. Over the past 15 years, several new techniques have been developed and are being implemented to facilitate breeding of improved crop varieties. Compared with traditional breeding, these techniques are expected to increase the precision of making changes in the genomes and thereby reduce the time and effort that is needed to produce varieties with new traits that meet new requirements [31] or with reintroduced traits that have been lost during domestication [57]. It is expected that the number of off-target mutations will reduce in the future [49]. While the first generation of GE-plants focused mainly on herbicide resistance and insect resistance, the genetic and epigenetic knowledge has dramatically increased in recent years. The genome sequencing of hundreds of genotypes and the mining of allele diversity in major crops and populations of landraces and wild relatives allow the genetic engineering of a larger array of traits [79]. For example, for more sustainable potato cultivation, certain elite potato varieties can be equipped with various combinations of resistance genes to the prevalent pathotypes of *Phytophthora infestans* by cisgenesis. However, combining resistance genes from different wild sources is also possible with traditional breeding in combination with the use of molecular markers but will take longer [27]. Another example is that, by using genome-editing tools that enable the production of very precise changes, new disease resistances are expected to be created by switching off susceptibility genes, without affecting plant fitness [31].

Most frequent arguments of the organic sector against GE and related techniques are focused on the consequences of GE-techniques: on the environment, human health and the social position of the farmer. These arguments seem not always the most convincing arguments as risk perception is bound to cultural and socio-economic aspects that can change over time [2,4]. In other words, because of different risk perceptions, arguments of the organic sector may not be convincing for those that do not adhere the values of organic agriculture. Verhoog [37] considers the arguments based on the organic principles as more specific and more credible arguments. Awareness among scientists and policy makers has increased that it is important to acknowledge a pluriformity in public opinion and that scientists need to be open to concerns of the public [49,57,59,80].

We have argued that plant breeding is not only a technical activity to develop new cultivars, but that it is also about the organization of social environment for these activities, including law, policy, culture (values) and the market. There is a complex interaction between new innovations and the development of society [76]. Hence, breeding techniques are not neutral tools, but result from and represent paradigms (e.g., views on the organization of food production). Which breeding approaches and breeding techniques are most suitable for which farming systems depend on a complex of agro-ecological, socio-economic and cultural factors. Hence, worldwide food security is not only a matter of increasing productivity but is also shaped by a complex of socio-economic, cultural and political factors such as food sovereignty, access to land, seed and water, empowerment of farmers and rural populations and food distribution to non-farming populations in cities. Given the pluriformity in agro-ecological and societal contexts, we envisage breeding for organic agriculture to be organized in various ways to be able to meet this diversity in agro-ecological and societal contexts worldwide.

Thus far, only a few breeding initiatives are conducted specifically for and in OA ("organic plant breeding") [30,67]. However, their market is expected to grow rapidly in the future. Here we highlight three main directions to realize the organic breeding objectives: (1) cooperation with conventional breeding companies; (2) the development of technical innovative breeding strategies based on the principles of organic agriculture; and (3) of innovative organizational strategies such as participatory and collaborative approaches with farmers and other chain players. These three directions will be discussed below.

The first direction, cooperation with conventional breeding companies, is gradually becoming more realistic as the organic sector is growing and provides an interesting market for conventional breeding companies to address. IFOAM estimates the potential of the total market share around 20% when the sector adopts continuous further improvement of its farming strategies [15]. Already a large number of seed companies have proven interest in propagation of part of their conventional cultivar assortment organically and the next step is reshaping their breeding program for traits that are of importance for organic farming systems. Sooner or later, traits such as improved nutrient efficiency and improved root systems will also contribute to the sustainability development in conventional agriculture. However, currently only a few conventional breeding companies integrate the needs of organic farming into their program ("breeding for organic agriculture") [30]. Osman et al. [77] have described these interactions in more detail for the development of organic wheat variety profiles. It is an example of how the organic food chains can cooperate with conventional breeders.

However, collaboration with conventional breeding companies should not be the only strategy to achieve better adapted cultivars for OA. We also need to consider there has been a fast consolidation and monopolization of the seed market, with three global companies controlling over 50% of the market [81], replacing local family owned and public breeding activities. As a result, we have lost not only the genetic diversity of numerous local varieties and landraces [82], but also dramatically reduced the number of crop species used for our food production. This is important, as crop diversification has been identified as key for adaptation to environmental change [83]. This leads us to discuss the second and the third direction.

The second direction is to further develop technical innovative breeding strategies for OA. Several studies have demonstrated that the highest breeding gain for OA could only be achieved when selecting under the target conditions of organic farming [64,84]. This either requires breeding companies to include organic selection fields in the program [85] or involve organic farmers in the selection process [86]. Besides, the potential of within-crop diversity, such as composite cross populations in cereals and mixtures of modern cultivars [87], and breeding for mixed cropping systems [88] are being explored to enhance yield stability and the resilience of organic agro-systems.

The third direction is to improve the organizational aspects of breeding for OA, e.g., to further develop participatory plant breeding and collaborative breeding involving farmers and other chain actors. Such can be powerful and cost efficient approaches for developing a diverse assortment of locally adapted and open pollinated cultivars for a large range of crops [86,89,90], with the possibility to achieve equal or higher yield compared to modern high yielding F1 hybrids due to optimized use of local/regional adaptation [91]. An example is the case of open pollinated sweet corn development in USA [92]. The role of farmer seed networks in conservation of agro-biodiversity and the development of new genetic diversity and varieties in that way contributing to local food security was highlighted in various studies across the world, including developed and developing countries [93–95]. However, to upscale such participatory and collaborative breeding, additional new organizational approaches are needed that focus on the financial aspects of breeding and that involve other chain players and the consumers in plant breeding [67]. In Europe and USA several initiatives are exploring new concepts of open source seed (considering seed as a common good) as alternatives to the monopolization of the seed market, but requires new concepts of financing to be developed [96]. In recent years, several traders, retailers and supermarkets are actively involved in supporting organic breeding. Following the IFOAM principles, various organic breeding initiatives consider it also important to involve consumers to raise awareness on fair seed developments and their role as consumers [96]. For consumers not only price, taste and quality is important, but also the management of biodiversity. The actual price consumes are willing to pay for products that foster biodiversity management depends on how they are approached in shops [97]. It is a direction that requires further exploration. Such approach is very different from current developments in conventional breeding on reshaping licensing of patents that are only accessible for large breeding companies [98].

To summarize, the organic sector needs to further develop various breeding approaches that fit with the principles of the IFOAM. This will also require political dialog and public intervention in agricultural research to support new concepts of organic plant breeding in which the whole value chain up to the final consumers are included [99,100]. To facilitate such developments, interdisciplinary research is needed to integrate knowledge from the technical and social sciences [7]. A pluriformity in breeding approaches suited for OA considering different agro-ecological and socio-economic contexts will allow breeding for local adaptation and niche markets. This will contribute to the maintenance of diversity of our crop plants and, thus, lower risks of total crop failure due to extreme weather events expected due to climate change.

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ANALYSIS

Why are ecological, low-input, multi-resistant wheat cultivars slow to develop commercially? A Belgian agricultural 'lock-in' case study

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The use of multi-resistant cultivars allows a significant reduction in fungicide use in low-input cropping systems. However, many major wheat cultivars used in Europe remain sensitive to frequent diseases and require fungicide protection. This paper aims at understanding the factors explaining the low level of adoption of multi-resistant wheat cultivars in Wallonia (Belgium). Cultivar adoption has been an important topic of research, but few analyses have been done in Europe in the past decades. We used a systems approach combining a survey among stakeholders in the food chain and a systematic analysis of the publications of extension services. We identified twelve factors impeding wider adoption of multi-resistant cultivars. These factors explain why current wheat-cropping systems are maintained in a 'pesticide lock-in' situation, an economic concept that could be used more frequently to study agricultural innovations. Considering these intangible 'barriers' to current and forthcoming innovations is a first step towards a more comprehensive policy to promote sustainable agriculture. Similarities between Wallonia and France are discussed and methods of promoting wide use of resistant cultivars are proposed.

1. Introduction

Disease-resistant cultivars have been bred throughout the world for a long time and are numerous among commercially available wheat cultivars. Their advantages for producers are, first, a direct economic benefit (the reduced costs of fungicides and fuel due to a reduced need for fungicide applications) and, secondly, an indirect social amenity (reduced time and hassle devoted to the control of crop health and to spraying). These two benefits are of greater importance when cereal prices are low (low prices make the application of fungicide less cost-efficient) and, to a lesser extent, for farms which are expanding in size with a constant workforce. These were two of the main current trends of cereal production in Europe when this research was conducted. Wheat prices in Belgium were as high as 226 €/T in 1983 (Conseil Supérieur Wallon de l'Agriculture, 2002) but decreased thereafter, dropping below 100 €/T in 2004–05.

While the main benefits of disease-resistant cultivars are for farmers, society as a whole has a lot to gain from them as they contribute to a general reduction in pesticide use, which is recognised as a significant and worthwhile public objective because of the environmental and health problems linked to the use of pesticides (Wilson and Tisdell, 2001). However,

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disease-resistant cultivars do not systematically become best-selling cultivars. On the contrary, many best-selling cultivars prove to be weakly resistant to one or more important diseases, and rely completely on fungicide protection. Why do disease-resistant cultivars fail to reach the top? Is the yield lag between the hardiest disease-resistant cultivars and the highest-yielding cultivars the only explanatory factor for this, as the analysis of the 'yield penalties' of disease resistance in plants may lead us to conclude (Brown, 2002)?

The aim of this study is to understand all the factors impeding the use of the best disease-resistant cultivars by farmers. We tackled this objective with a case study focusing on one cereal, winter wheat, in one specific European region, the cereal-growing part of Wallonia (Belgium).

Winter wheat is the main cereal in Wallonia, comprising 70% of the area devoted to cereals, with a mean yield of 8.5 t/ha. Some 8000 farmers grow winter wheat on 130 000 ha. Most of the winter wheat is grown under a conventional high-input cropping system, with the exception of organic wheat and low-input systems under agri-environmental schemes for which a premium is given (requiring reduced sowing density, use of maximum one fungicide application, no use of straw shorteners, greater attention to cultivar choice and fertilisation). Each of these two exceptions represents about 1% of the wheat surface. Wheat is used for animal feed, human consumption and the starch industry.

The most problematic diseases in the wheat cropping systems under consideration are *Septoria* leaf blight (SLB), brown and yellow rusts, powdery mildew and, more recently, *Fusarium* head blight (FHB) (Smith et al., 1988; Lucas, 1998; FUSAG and CRA-W, 2005). SLB has an important economic impact on wheat production (yield and quality). It is caused by *S. nodorum* and *S. tritici* and its impact has become more pronounced in recent years, due in part to the increased genetic resistance of wheat to other foliar pathogens such as powdery mildew (Eyal, 1999). FHB is a cyclic disease, occurring once every 3 to 5 years (Champeil et al., 2004a). Once a limited disease, to which no particular attention was paid in the region, FHB gradually became a major public concern as data on the public health problems associated with fusariotoxins, especially deoxynivalenol (DON), accumulated. FHB occurs in many regions of the world with yield losses reaching 50% under unfavourable conditions (Parry et al., 1995). Yield losses are limited in Wallonia, but mycotoxin contaminations are a major concern in unfavourable years such as 2002, when over 35% of the samples analysed exceeded the EC recommended DON level (Chandelier et al., 2003b). Maximal DON levels vary depending upon the final use of the grain: baby food, human food or animal feed.

Fungicide applications differ from one plot to another according to agro-meteorological conditions, pathogen epidemics and the crop cultivar, as well as the farmer's objectives and aversion to risk. Average quantities of the active ingredients for wheat were reduced during the period 1991–2000: the total quantity of crop protection products dropped from 4.7 to 3.2 kg/ha and the quantity of fungicides from 1.7 to 0.7 kg/ha (Ministère des Classes Moyennes et de l'Agriculture, 2002). However, the cost of crop protection rose from 124 to 162 €/ha between 1994/95 and 2000/01 (Groupe de travail de la filière 'Céréales', 2003). Farmers make between one and three fungicide applications a year (usually one or two) and each application generally consists of mixtures of fungicides, mainly triazoles and strobilurins.

Fungicides for both diseases are problematic. The appearance of *Septoria* populations resistant to strobilurins fungicides has been rapid and has occurred on a European scale. In a three year period, the effectiveness of this new active ingredient decreased so markedly that it is now advised to use it only in mixtures with other substances (Moreau, 2004). Fungicide applications for FHB are only weakly effective: applications must be made during the very short flowering period, when kernels are sensitive, which allows the farmers only limited flexibility. Even the best active ingredients only control disease incidence by half (Chandelier et al., 2003a). In certain cases fungicide applications can even stimulate mycotoxin production. This has led scientists to advise that mixtures of fungicides should be applied (European Mycotoxin Awareness Network, 2005).

In 2004, eighty cultivars were bred in Belgium, of which 44 cultivars were registered on the Belgian national cultivar catalogue (Ministère de l'Agriculture, 2005) while the others were available through the European cultivar catalogue. The public extension services in Wallonia conducted field tests on a great number of these cultivars: in 2004, 52 were assessed in the *Livre Blanc sur les Céréales* (White Book on Cereals, see below) for basic characteristics such as yield or phytosanitary contribution to yield (rate of 'loss' of untreated plot against treated plot, in percentage of kg/ha).

The extension services conducted a further analysis of 24 'main' or 'recommended' cultivars (only 11 of which are included in the Belgian catalogue). Additional information, such as cultivar susceptibility to diseases, is available to farmers for these cultivars. Scores for cultivar resistance to diseases are a synthesis of data from experimental fields and visual observations in farmers' fields. Four levels of resistance are determined (with 4 being the highest resistance) for each of the four most common diseases (FHB, SLB, brown rust, yellow rust). In the present paper, we define levels 1 and 2 as 'poor' and 'low' resistance respectively, while we speak of resistant cultivars for levels 3 and 4. In 2004, twelve out of the 24 main cultivars had poor or low resistance to SLB and five to FHB. Only six were multi-resistant (level 3 or 4 for each of the four common diseases). These cultivars accounted for 26 to 31% of the official seed propagation areas in Belgium between 2003 and 2005.

Section 1 of this paper presents the systems approach we employed. Section 2 describes the twelve factors explaining the weak adoption of existing multi-resistant cultivars. In the discussion section, our Belgian findings are discussed in comparison with neighbouring France, and with the help of the 'pesticide lock-in' concept. Possible ways of changing the situation are also discussed.

2. Method

Our qualitative and multidisciplinary approach is one of a number of soft-systems approaches (Checkland, 1981; Ison et al., 1997). Soft-systems approaches are useful to understand and integrate agronomical, socio-economic and organisational dimensions of complex problems. While the method is used here to study technology adoption, its principles have also been used to tackle other complex problems such as why and when food systems fail to deliver safe products (Hennessy et al., 2003) or to discover impediments to the development and use of non-chemical alternative strategies to pesticides (Diamand, 2003).

Our method comprises three methodological steps. First, a survey of stakeholders in the cereal agricultural sector and food chain was conducted in Wallonia during the 2004/05 winter. It consisted of 25 in-depth semi-directed interviews. Technical advisers from public extension services, employees of private firms and scientists were interviewed about FHB and SLB. The survey was conducted according to the '*de proche en proche*' ('friends of friends') method (Blanchet and Gotman, 2001), which aims at interviewing influential stakeholders rather than statistically representative samples. In this method, the people interviewed are questioned about who are the most relevant stakeholders for the issue under consideration. Only the most frequently mentioned people are then interviewed. In our case, we stopped the survey when new interviews were not bringing any new information. For farmers, we took account of the results of a larger survey among a hundred farmers in the cereal-growing region of Wallonia, which gave useful results on farmers' decision-making processes (Marot et al., 2005).

The questions in the survey were directed at understanding the use of several integrated pest-management strategies. However this paper focuses solely on the use of disease-resistant cultivar. Semi-directed interviews were based on a series of questions common to all interviews, but allowed for secondary, in-depth questions that depended on the answers being given by the interviewee. Examples of questions raised in all interviews are: What are the current agricultural strategies available to stop or reduce these diseases? How far do farmers use them? Why do farmers not use disease-resistant cultivars? Is the situation of disease-resistant cultivars different from a few years ago? Why? Examples of specific questions are: (to breeders and seed companies) What are your priorities for breeding programmes? (to scientists) What kind of research projects on disease control have been conducted in the past, and are being conducted currently?

Secondly, the contents of the *Livre Blanc sur les céréales* (White Book on Cereals), a bi-annual handbook published by public research institutions and extension services, was analysed for the period 2000 to 2005 (FUSAG and CRA-W, 2005). The *Livre Blanc* is the main written source of independent technical advice for wheat producers in Wallonia. The Gembloux Agricultural University (FUSAG) and the Wallonia Agricultural Research Centre (CRA-W) edit it. This bi-annual handbook is composed of regular papers updating the technical advice on main themes, and occasional shorter papers on current issues. The main purpose of the handbook is to popularise results from the latest research and give the best science-based advice to farmers.

The 125 published papers in the period 2000 to 2005 were first classified according to their main subject, such as 'fertilisation', 'wheat quality', 'weeds', etc. All papers related directly or indirectly to diseases and crop protection were selected: these included regular papers (up to 60 pages long) on 'wheat crop protection' and 'fungicides' as well as occasional shorter papers on 'head blight and mycotoxins', 'wheat cultivars and diseases', 'organic wheat' and 'agri-environmental schemes'. The 31 selected papers accounted for 43% of the total pages of the publications during the period, and contained 205 tables presenting results from experimental research carried out on research sites or on-farm experiments in Wallonia during this period. These tables were systematically analysed (see Table 2).

Thirdly, a desktop search for grey literature from the cereal sector and a literature review covering the various domains involved completed our research. The combination of these different sources allowed us to compile information about how cereal production functions from existing experimental research as well as from the human experience of a diversity of professional stakeholders. It enabled us to take into account qualitative as well as quantitative aspects, and to crosscheck and verify the results obtained, for example by analysing technical data in the light of the 'real world'.

3. Results

Our approach uncovered twelve factors impeding a broader use of multi-resistant wheat cultivars (see Table 1). These factors are technical and socio-economic, obvious and less obvious. They are grouped according to the level of the agri-food chain at which they exert an influence: farmers, the market, public extension services and research, public regulation and past agricultural policies.

Several factors are direct adoption factors that have a direct influence on farmers' adoption of multi-resistant cultivars. Others, such as Factors 6 and 10, are indirect determinants of innovation that influence the scientific and commercial development of quality multi-resistant cultivars.

Table 1 – Factors impeding the systematic use of multi-resistant wheat cultivars

Farmers
1) Direct cultivar choice criteria of farmers: disease resistance comes only after gross yield, resistance to lodging and commercial quality
2) Incomplete resistance of resistant cultivars and the unpredictability of epidemic development
3) Limited number of cultivars resistant to all frequent diseases
Market
4) Contradictory objectives of crop protection and seed departments in supply companies (which disadvantages resistant cultivars)
5) Influence of supply companies' salespeople on farmers' practices
6) Breeding history and breeding objectives of seed companies
Public extension services and research
7) Omnipresence of gross yield and absence of economic optimum estimates
8) Concentration on one cultural system at the expense of alternative systems
9) Perception of, and information given about, resistant cultivars
Public regulations
10) Cultivar registration norms
11) More important challenges: food safety, traceability, etc.
Past agricultural policies
12) Payments based on output influenced cultivar choice towards highest-yielding cultivars

3.1. Factors at the farmers' level

3.1.1. Criteria for cultivar choice

The first factor is the direct criteria for cultivar choice by farmers. According to extension services officers, resistance to diseases comes into play only after four other main criteria (gross yield, resistance to lodging (yield security), earliness, and commercial quality) have been considered. A survey among 100 farmers confirmed that the main criteria were yield (main criteria for 64% of farmers) and commercial value (22%), while resistance to diseases ranked only third (14%) (Marot et al., 2005). Extension services officers also reported that the prestige of maximal gross yield remains predominant in farmer-to-farmer contacts, and a glance at the agricultural press confirms that this is indeed a powerful criteria in the whole agricultural sector. Farmers thus generally consider resistant cultivars only if they rank best for yield, which cuts out a number of them.

3.1.2. Incomplete resistance of resistant cultivars

The second factor is the incomplete resistance of resistant cultivars and the unpredictability of the annual prevalence of the various diseases. Few cultivars are completely resistant to disease and degrees of resistance may change from year to year due to agro-meteorological conditions and pathogen evolution. This means that the risk of extensive disease damage is unpredictable, and it exists for almost all cultivars, as complete resistance is rare. As a consequence, the actual benefit of choosing resistant cultivars can only be fully assessed at the end of the season, which is no problem for a scientist, but not very satisfactory for a farmer.

3.1.3. Limited number of cultivars resistant to all frequent diseases

The third factor is the limited number of cultivars that are resistant to all frequent diseases. Few cultivars have a high level of resistance to each of the four most common diseases in the region (FHB, Septoria leaf blight, brown rust and yellow rust). Most cultivars resistant for one disease have at least some susceptibility to one or two of the other diseases, which makes the choice of resistant cultivars harder as all diseases are expected to occur from time to time. In 2004, only 5 out of the list of 24 main cultivars had 'good' (level 4) resistance to all four diseases. Some fungicide applications are thus needed even when resistant cultivars are used.

3.2. Factors at the market level

Private stakeholders influence crop protection practices in three ways: (a) an internal bias in supply companies in favour of fungicide rather than seed sales; (b) a bias towards fungicide applications among supplier salespeople; and (c) the low priority attached to breeding for disease resistance in seed companies.

3.2.1. Internal bias in supply companies in favour of fungicide rather than seed sales

Supply companies have a preponderant role in the cereal sector: these firms sell crop protection products, fertilisers, seeds, advice and agricultural machinery to farmers and also collect their cereal output. In Wallonia, two large organisations share two thirds of this market (one private firm and one farmer cooperative). In each of these two supply companies, the seed department accounts for a very small share of the sales (6–7%). Crop protection products and fertilisers are much more profitable departments. According to a seed-department head, this internal imbalance greatly influences the firms' activities, including the choice of cultivars on which the organisation takes out licences. The contradiction lies in the fact that a seed department should promote the most resistant cultivars, but this is not a priority for the crop-protection and fertiliser departments, which focus on cultivars with the highest yields. Suppliers primarily make money from fungicides and not from seeds. The fact that seeds and crop protection products are sold by the same distribution networks thus has a key influence on the weak development of disease-resistant cultivars.

3.2.2. Bias towards fungicide applications among supplier salespeople

The second factor is also located with supply companies. Local salespeople from the supply companies have the greatest influence on farmers, especially since the network of regional public extension officers has been dismantled. They are the only external technical advisers that have direct and regular contact with every farmer. Salespeople advise farmers on cultivar choice as well as on crop protection products and fertiliser choice. They are partly paid according to sales, which induces a second bias in favour of high-input systems. The highest-yielding cultivars that perform best under high-input conditions are thus promoted even if they are poorly resistant to diseases. Fungicide application is promoted, even in situations in which it is unnecessary. Indeed, a second fungicide treatment is often suggested, even when it is neither necessary nor profitable, as farmers, especially risk-averse farmers, tend to think of fungicides as forms of insurance. This factor was mentioned by public extension officers in interviews, and is also present in their articles in their annual handbook (FUSAG and CRA-W, 2005). Supply companies deny it.

3.2.3. Low priority attached to breeding for disease resistance in seed companies

The third factor relates to breeding companies. The real importance of breeding for resistance is controversial. While resistance is often mentioned as a priority in breeding programmes (Eyal, 1999), some private breeders recognise that resistance is not as important an objective in their work as in that of public breeding institutions. Real progress in resistance improvement takes a long time: public breeding centres have fewer constraints to engaging in this work than private breeders, which have short-term profitability constraints, such as 'put at least one cultivar on the market a year' to remain competitive.

This lack of interest does not mean that modern cultivars have lower resistance levels than old cultivars, but that there has been an under-investment in this breeding objective. During the three last decades, the existence of fungicides and the focus on high-input systems has led to a greater focus on yield than on resistance. As a consequence, breeding for resistance has not been very profitable. The effort put into breeding for resistance to diseases has thus been insufficient, compared to what breeders could now offer, in terms of commercial cultivars, if their main objective had been to produce hardy cultivars. In addition, breeding-for-resistance programmes have focused on vertical resistance rather than horizontal, polygenic, resistance. This strategy is not sustainable as the example of the breakdown of *Yr17* resistance to yellow rust shows (Bayles et al., 2000).

3.3. Factors at the extension services level

Public extension services influence cultivar choice and agricultural practices. In Wallonia, public extension work on wheat production is run by the Wallonia Agricultural Research Centre (*Centre de Recherche Agronomique de Wallonie*, CRA-W) in conjunction with the Gembloux Agricultural University (*Facultés Universitaires des Sciences Agronomiques de Gembloux*, FUSAG) and the Faculty of Bioengineering at the Catholic University of Louvain (*Université catholique de Louvain*, UCL).

To study the role of public extension services, we relied both on interviews with stakeholders and the analysis of the contents of the *Livre Blanc* between 2000 and 2005. The great majority of experimental research concerned the influence of one variable – such as sowing date or cultivar choice – on gross yield (46.3%), the phytosanitary contribution to yield (27.3%), cultivar disease-susceptibility estimates (10.2%), and the development of disease in a crop (9.8%) (Table 2).

Three factors that interfered negatively with a wider use of resistant cultivars by farmers were: (a) the omnipresence of gross-yield calculation and the absence of economic-optimum estimates; (b) the perception of resistant cultivars by extension services officers; and (c) the concentration of applied research on one cropping system. The results of interviews and observations of advice given by extension services to farmers in public presentations were consistent in this respect.

Table 2 – Experimental research reported in the *Livre Blanc* between 2000 and 2005

	Number (n=205)	Percentage (%)
Type of result		
Influence of one variable on gross yield (kg/ha)	95	46.3
Phytosanitary contribution to yield (kg/ha)	56	27.3
Cultivar disease-susceptibility estimates (scale of 1 to 4)	21	10.2
Disease development in a crop (% affected area)	20	9.8
Difference in revenue between various cropping systems (expressed in kg/ha)	16	7.8
Mycotoxins estimates (DON or mg/kg)	7	3.4
Type of field tests		
Long term experiment (over 3 years)	37	18.0
Comparison between various cropping systems	35	17.1
Comparison including low-input systems under agri-environmental schemes	20	9.8
Tests on organic fields	2	1.0

3.3.1. *Omnipresence of gross-yield calculation and absence of economic-optimum estimates*

Public extension work, as measured by the content of the *Livre Blanc*, relies systematically on calculations of gross-yield, and pays little attention to estimates of economic optimum. While nearly half of the results of experimental cereal research focused on gross yield (46.3%), only 7.8% employed a more comprehensive economic analysis by including the costs of inputs for cropping systems which made a moderate or intensive use of inputs (fertilisers, fungicides). In the five-year period, only one paper developed a full economic analysis in which units were euros/ha and not kg/ha. Other analyses (28%) attempt to 'translate' costs of inputs such as crop protection products or spraying applications and fuel into 'kg/ha equivalents'.

This is particularly surprising because the results of the few analyses on economic optimum in cereal production gave original and interesting results. Some economic comparisons between high- and low-input cropping systems were carried out in the context of agri-environmental schemes in the early 2000s (Buyze et al., 2003; Dekeyser et al., 2003, Soete et al., 2003). Their conclusions were clear: the quest for the highest gross yield is not the best strategy to maximise net gross margin when wheat prices are low (which was the case at that period). Instead, a choice of disease-resistant cultivars in low-input systems gave the economic optimum when agri-environmental premiums of Common Agricultural Policy (CAP) second pillar were taken into account. Soete et al. (2003) are unequivocal: 'Considering the latest four years of results, the economic optimum was reached by the low-input system complying with agri-environmental schemes. The combination of input reductions and agri-environmental premiums legitimises the 5-year commitment to agri-environmental schemes'.

Paradoxically, this type of result has not been published since 2003. Results of low-input systems were nevertheless confirmed with additional, unpublished results: a few resistant cultivars were even the most profitable in low-input systems without agri-environmental premiums (Dekeyser et al., in press). Results from a French research network on low-input systems showed the economic advantages of such systems in comparable cropping systems (Felix et al., 2005; Rolland et al., 2005). The situation in France is discussed in more detail in Section 4.1 below.

However the published information about these economic comparisons was limited. In the *Livre Blanc* results from these economic comparisons were generally published as short occasional papers on agri-environmental schemes (during the time these schemes had a bad image as farmers had to commit to them for five years to get the premiums). Only once, in 2001, were the results integrated into the general section dealing with the conventional production of wheat. Actually, public extension services consider that supplier salespeople who have direct contact with farmers distribute the most relevant information from the handbook. The place of the information in the handbook would thus not have great importance. However this might not be true for this type of information, as suppliers might minimise the importance of such results because they rely on sales of fungicides and fertilisers and have thus no interest in promoting low-input systems. As one manager put it clearly in an interview: 'Between ourselves, calculation of gross yield (instead of economic optimum) suits the whole business: the agricultural press, the phytosanitary companies, etc. It leads to greater consumption. Everyone has an interest in it'.

The results of our survey were consistent with these findings. During interviews, the issue of economic optimum was only raised by advocates of resistant cultivars. Public extension officials either dismissed such calculations or discussed the many difficulties in carrying out the calculations. These difficulties comprise the costs of implementation, the fact that the results were less immediately comprehensible than gross yield, the fact that the calculation was more complex as more variables have to be taken into account, and the difficulty of adopting a standard calculation when some farmers take the costs of labour or oil into account and others do not. A few were indifferent to economic-optimum estimates which seemed to them an unimportant measure for farmers, since their variable expenses are low compared to their fixed expenses such as farm rental and loan repayments.

Whether farmers calculate their economic optimum themselves or not is thus considered an open question by scientists and technical advisers in the cereal sector in Wallonia. No surveys of farmers' practice in this respect have been carried out in the region. However, most scientists and public extension officers think that farmers, or even agri-managers, do not calculate economic optimums. In any case, it seems rather unlikely that a farmer could, without the appropriate information and tools, analyse the results from 20 to 70 cultivars and compare the results of three different cropping systems (low, moderate and high-input)!

3.3.2. *Perception of resistant cultivars by extension services officers*

According to prominent public extension officers, cultivar susceptibility to a disease is 'the probability of having to spray at any given time'. A resistant cultivar 'raises the chances of not having to apply two fungicides and allows greater flexibility in the time of application' [which is very important for farmers who may be busy with livestock management or other activities at a particular time] 'without excluding an intervention' (Couvreur and Herman, 2002). Public extension officers thus promote their own perception of resistant cultivars: while they advise choosing cultivars resistant to the most systematic diseases (Septoria leaf blight and brown rust), they fail to emphasis the economic benefits of resistant cultivars in low-input cropping systems.

3.3.3. *Concentration of applied research on one cropping system*

The third element that we identified as a factor impeding the wide use of the best resistant cultivars is the concentration of experimental research on one cropping system, at the expense of alternative systems. In the *Livre Blanc*, there were six research papers on agri-environmental schemes between 2000 and 2003, but only two one-table two-page papers on organic wheat, one in 2001 and one in 2002. During the entire period, only 10.6% of the research tables presented to farmers concerned agri-environmental schemes, and only 1.1% covered organic wheat. This research was exclusively published in specialised occasional papers. Regular papers on general wheat production only covered research on agri-environmental schemes once in the entire period, and never compared conventional and organic wheat production systems. Occasional papers focusing on agri-environmental schemes formed the vast majority of published research on both the economic optimum (12 out of 14 research tables) and the comparisons between different input levels (21 out of 32 research tables).

Large-scale comparisons between different cropping systems, including organic systems, are indeed extremely rare (Champeil et al., 2004b).

The experimental conditions of cultivar field tests also reflect this concentration on one particular cropping system. Experimental fields are sprayed twice with fungicides to fully protect the plant from disease damage, as the main objective is the assessment of the gross yield potential of cultivars. Other considerations also play a part, such as the desire of farmers who host cultivar field tests to show 'nice' fields. Results from the main network of cultivar tests influence not only farmers' choices but also seed companies' strategic decisions such as the areas devoted to seed propagation. The decision to double-spray experimental areas (instead of systematically comparing the results with one and two applications) may thus induce farmers to adopt the same strategy, even when it is not the optimal strategy from an economic point of view.

Besides, it was evident in our survey that scientists had a poor knowledge of results from non-experimental research. The stakeholders and scientists we interviewed could hardly cite any local socio-economic research or surveys on farmers' strategies, decision modes or use of external information. One prominent scientist only knew of two: one in 2004 and another in 1985 (Marot et al., 2005; Duveiller et al., 1985). Studies on the development, advantages and drawbacks of agri-environmental schemes such as low-input wheat systems attracted only limited interest from the agricultural research community. Data on the market share of each commercial cultivar, on cultivar genealogy and heterogeneity, on fungicide application strategies and crop rotation schemes used by farmers was unavailable. However all this information is necessary to assess how improvements in integrated pest management could be achieved. Low commitment to social sciences and non-experimental research in general results in a limited openness to critical research on and analyses of the organisation and activities of the food chain.

When combined, the three elements listed above give a weak signal to farmers that resistant cultivars and alternative cropping systems could be a profitable system. Publications by extension services, and the agricultural press in general, matter. As communication theorist Cohen observed what became a widely accepted fact in communication 'the press is significantly more than a purveyor of information and opinion. It may not be successful much of the time in telling people what to think, but it is stunningly successful in telling its readers what to think about' (Cohen, 1963). A systematic calculation of gross yield instead of economic optimum, a focus on high-input systems and a disregard for low-input systems all influence cultivar-choice strategies.

3.4. Factors at the public regulations level

Public regulations also greatly influence agricultural practices. We identified several public norms and regulations that had a direct or indirect influence on farmers' behaviour.

3.4.1. Cultivar registration norms

In Belgium, experimental tests for registration are historically conducted with fertiliser use matching farmers' practices but under no-fungicide conditions. These conditions are thought to positively influence the acceptance of disease-resistant cultivars, as they perform better than susceptible cultivars under these conditions. New cultivars are assessed following a grid of criteria and receive a positive or negative grade for each criterion depending on whether its results are better or worse than the mean for that criterion. This grade is then multiplied by a weight according to importance of each criterion (1 for yield, 0.9 for resistance to lodging, 0.2–0.3 for resistance to each of the four diseases). Grades are finally summed to give a final mark that results in cultivar acceptance if it is positive. The impact on resistant cultivars is thus only moderate: cultivars can compensate for high susceptibility to a disease with a high score for yield. The procedure may dismiss some hardy cultivars: resistant cultivars that perform well under low-input conditions may not outperform higher-yielding cultivars in highly fertilised conditions.

3.4.2. Prevailing challenges in the agri-food chain

Two important challenges, food security and food traceability, conflict with pesticide-reduction efforts and the promotion of integrated pest management. These socio-economic issues, which are not directly related to crop protection, worry all stakeholders a lot more than a reduction in fungicide use and this fact has to be linked with cultivar use. New constraints such as the Integral Management of Food Chain Quality, monitoring contaminants in the food chain, and traceability schemes are the number one problem for all stakeholders. European and Federal public regulations are being implemented or even anticipated at all levels. Our survey showed that this puts a heavy burden on all public and private organisations involving costs, human energy and time. In comparison, a recent Federal programme of pesticide reduction was not even mentioned in any interview, and prominent public stakeholders were not aware of it. Public extension services, civil servants in administration, and scientists involved in applied cereal research have finite time, energy and resources; they use these to deal with the most important current priorities. Food safety and traceability are thus indirectly reducing the attention stakeholders can pay to the importance of cultivar disease resistance or broader pesticide reduction programmes (FHB is an exception here, as we will see below).

3.5. Factors based on past agricultural policies

A number of factors relate to the importance of gross yield and the biases it induces in cultivar and cropping-system choices by farmers. For some time, farmers have received agricultural subsidies based on their output level. As these payments were a major part of farm revenue, this aspect of CAP is largely responsible for the bias towards the high yield. It pushed farmers towards the quest for the highest achievable yield, and influenced both breeding objectives and the evaluation criteria in extension services.

4. Discussion

This case study is limited to a specific crop, a few diseases and a particular region yet our results have a broader significance. Firstly, comparable situations exist in other countries, especially in neighbouring France (Section 4.1). Secondly, our analysis leads us to depict the current cultivar use and crop protection situation in Wallonia as an example of a 'pesticide lock-in' situation (Section 4.2). Thirdly, we discuss the ways of promoting a wider use of multi-resistant cultivars and low-input systems (Section 4.3).

4.1. Comparison with other situations

The existence of factors explaining the weak adoption of disease-resistant cultivars has also been analysed in other agri-food chains in Belgium. Thirteen factors explain the current failure of scab-resistant apple trees to become the main commercial cultivars, despite the fact that they can save up to 70% of the necessary fungicide treatments (Vanloqueren and Baret, 2004a).

The comparison of our results with those in other countries is not straightforward. Few recent analyses of cultivar adoption in Western Europe exist, since research on this topic has been almost completely abandoned in developed countries. It is gaining a new momentum with the growth of genetically modified crops, yet there is currently very little experience of this in Europe, with the exception of maize in Spain.

The use of multi-resistant cultivars may be seen as a component of truly 'integrated' pest management (IPM). However, the IPM adoption literature is also limited, especially in Western Europe. Following Jeger (2000), there has been too little analysis of situations in which constraints to the adoption of alternative pest control strategies have been overcome. IPM is a process that includes a wide array of methods and products: resistant cultivars are only one component of it (Ehler, 2006). The factors leading to the adoption of multi-resistant cultivars are not directly comparable to those involved in the use of treatment thresholds, conservation measures, beetle banks, etc. There are however similarities between the factors we identified and the constraints to IPM adoption in the US identified by Ehler (2006). The first is the presence of conflicts of interest among private technical advisers employed by pesticide companies. The second is the fact that pesticides can be a cheap insurance policy: we mentioned the incomplete resistance and unpredictability of epidemic development as a negative factor in adoption, and these factors are directly linked to risk (and thus to insurance). The third is the current cultural routines of agricultural research scientists. Ehler mentions the resistance of scientists to a true integration of the pest disciplines, while we identified negative factors such as the concentration of research on one cropping system, the way resistant cultivars are assessed, and the omnipresence of gross yield rather than the economic optimum as the main reference point.

The comparison of our analysis with the situation in France is most relevant. France borders Wallonia, and faces a comparable situation as far as resistant cultivars and low-input systems are concerned. According to official surveys among farmers, multi-resistant hardy cultivars represented less than 3% of French wheat area in 1999 (INRA, 2001), but this had increased to 16% by 2004 (Rolland et al., 2005). The French definition of hardy cultivars fits within the context of low-input systems: it includes productiveness and multiple disease resistance, but allows susceptibility to one disease, such as FHB (Rolland, personal communication). Such cultivars were studied in France in a large network of field tests between 1999 and 2002 (Meynard et al., 2003), which were further extended in 2003–2005. The results from this programme were published in the agricultural press, which is also available in Belgium (Felix et al., 2005), as well as in scientific communications (Rolland et al., 2002, 2003; 2005; Loyce et al., 2006). The 2003–2005 programme concluded that in 45 out of 66 locations, the combination 'hardy cultivar-low-input system' gave the highest economic margin.

Hardy wheat cultivars are presented as a success story of public agricultural research. However, the historical analysis of contemporary plant science research in France by Bonneuil and Thomas (in press) demonstrates that the development of hardy cultivars depended solely upon the persistence of a few scientists who swam against the flow until the late 1990s, when wheat prices had fallen and agricultural professionals start to look at their results differently. The main factors counting against disease-resistant cultivars in France were similar to those discussed in the Belgian situation. Impediments run from the strong political wish within research institutions to invest in hybrid wheat and plant biotechnologies rather than in traditional plant breeding for hardy cultivars, to the unwillingness of public technical institutes – which run the main agricultural journals – to publish the results of field-test research and economic-optimum analysis of hardy cultivars in low-input systems. The negative role of farmer cooperatives which are input suppliers, and of extension services, has also been mentioned as a factor working against the development of hardy wheat cultivars (Meynard and Savini, 2003).

The role of French private breeders in the development of hardy cultivars is controversial among scientists and stakeholders in the cereal sector. While a few breeders have been involved for decades in the development of hardy cultivars, and have produced sufficient cultivars to fit all needs today, it is argued that the main farmer cooperatives and breeders (some of which are partly owned by agro-chemical companies) have long promoted cultivars best adapted to high-input systems. The cultivar registration norms have been a constant bone of contention and site of power struggles between promoters of hardy cultivars and promoters of high-input systems (Bonneuil and Thomas, in press). Concentrating plant breeders' efforts on horizontal, polygenic resistance is a more sustainable strategy than focusing on vertical resistance, but not all breeders have yet made the transition.

4.2. *Pesticide lock-in*

Lock-in and associated path-dependence concepts have been suggested to explain the stability of socio-technical systems, particularly the sensitivity of competing technologies on initial conditions when increasing returns occur (David and Arthur, 1985; Arthur, 1989). One technology may become dominant over others that perform similar functions and compete for adoption by economic agents, even though it has inferior long-run potential. This 'path dependant' process is self-reinforcing and may lead to a technological 'lock-in' situation in which the dominant technology excludes competing and possibly superior technologies (Liebowitz and Margolis, 1995).

The existence of path dependence and lock-in processes has been shown in the realm of agriculture (Cowan and Gunby, 1996) even though most of the path dependence literature focuses on technological change in industry. Lock-in situations have been observed in several agricultural situations and food chains, such as for the use of pesticides in cotton and cereals (Cowan and Gunby, 1996; Wilson and Tisdell, 2001), in animal breeding (Tisdell, 2003), and in specific cases of animal breeds or plant cultivars having a tremendous influence on their sector (examples in Belgium include the Bintje potato cultivar, the Belgian Blue Beef and the Holstein breeds (Stassart and Jamar, 2005)). The factors we identified in our study are comparable to the factors Cowan and Gunby (1996) found to be impediments to a switch from the historical use of chemical pesticides to integrated pest management (IPM) strategies: uncertainty, coordination problems, technology immaturity, inflexibility, technology inertia and path-dependence. If the presence of a few negative factors is not a barrier in itself, the build-up of numerous negative factors creates a lock-in situation.

In the course of the twentieth century, chemical pesticides gradually became the main pest control strategy. Modern wheat cropping systems are now 'locked-in' to a fungicide-dependency situation, even though the global situation (wheat prices, crop protection costs, cultivar characteristics, alternative crop protection strategies, available scientific knowledge) has changed. It has been shown that 'escaping lock-in' requires exogenous forces. Unruh (2002) analysed this situation for escaping our economy's dependence on fossil fuels. In the agricultural field, it has been shown that modifying practices in apple orchards demanded special efforts and conditions in the entire agri-food chain (Collet and Mormont, 2003; Vanloqueren and Baret, 2004b). Accepting that apples are very different from wheat, the same is probably true for the wheat sector.

Not all lock-in situations are completely locked. New conditions (such as tougher pesticide regulations, changes in cereal prices, changing consumer preferences, programmes of pesticide reduction, etc.) may 'dismantle' the lock-in. Even if we depict the situation as a lock-in, another observer may see only slow change. It depends on a qualitative assessment of the situation. However, naming the lock-in helps us understand that specific actions must be undertaken to get out of this static or very slowly changing situation.

4.3. *The transition to sustainability: paths to a broader use of multi-resistant cultivars and low-input systems*

An agricultural system can be locked-in to past solutions and get blocked from current optimal configurations. This situation is dependent upon past paths taken by farmers, extension services, agricultural policies and agricultural research systems. If the society as a whole considers this situation sub-optimal, scientists and the public authorities have a role to play in contributing to the transition to a more sustainable system.

As far as scientists are concerned, the phasing out of input intensification in wheat cropping systems induces a need for both long-term and large-range experimental studies, a neglected research area within agronomy (Meynard et al., 2003; Meynard and Savini, 2003). It also requires multidisciplinary research. There are various opportunities for public authorities to escape the self-reinforcing and path-dependant trend of input intensification. Obstacles to the use of resistant cultivars can be removed to accelerate their adoption. This can be a part of broader plans to accomplish pesticide-reduction programmes. A general switch to a systematic use of multi-resistant cultivars in the context of integrated pest management will certainly need more of a driver than the gradual adaptation of farmer strategies to cereal prices, as neoclassical economic theory assumes will be sufficient.

It is interesting to focus on two very different diseases. The case of FHB and associated mycotoxins is illustrative of how public authorities can still have an impact on food chain activities within globalised and free agricultural commodity markets. The prospect of a new European directive on mycotoxins led the whole cereal sector to anticipate it at all levels. Market stakeholders introduced maximal levels of mycotoxins in wheat even in the absence of binding rules. A few specialised food chains created a list of recommended cultivars while breeding programmes, private and public, integrated new sources of resistance to FHB. Research institutions launched specific task forces and research programmes such as risk forecast models or low-cost mycotoxins detection toolkits. These efforts were coordinated on the European scale for a chain-wide strategy (Scholten et al., 2002). However pesticide reduction efforts are only weakly coordinated in Wallonia and in France. Other countries, such as Denmark, have achieved great success with long-term pesticide reduction efforts.

The first channel through which public authorities may act is norms for cultivar registration. In a number of countries, minimal levels of cultivar resistance to FHB have been introduced as part of broader plans to control the risk of contamination of food chains by mycotoxins (Ruckenbauer et al., 2004; Snijders, 2004). Minimal levels of resistance to each of the most frequent diseases would be a strong incentive for breeders to invest more resources in breeding for disease resistance. Likewise, the registration procedure might include an ex-post assessment after a two- or three-year period: cultivars that lost resistance over time due to pathogen adaptation could be removed from the market or charged extra for registration maintenance.

Registration procedures should also be adapted to fit with low-input cropping systems (low fungicide and low fertiliser use) by testing cultivars in such conditions in order to promote hardy cultivars. These institutional innovations would have to be adopted on a European scale to have any real impact.

Secondly, extension services should be adapted to new socio-economic and societal trends. Public action must induce a paradigm shift to overcome strongly rooted socio-economic trends. Productivism (Walford, 2003), illustrated here by the prestige of maximum gross yield, must be replaced by objectives such as economic and environmental efficiency. Extension publications thus have to be remodelled; the single fact that they presently focus on yield, and not economic optimum, has great importance. As price conditions vary annually and cultivar turnover is high, research and extension should focus on answering a currently unasked question: 'Is the systematic choice of the best multi-resistant cultivars – and of low-input systems – the most profitable choice for farmers on a 3-, 5- or 10-year perspective?' Cultivar choice software may become a useful tool for cultivar choice (Barbottin et al., 2006). Economic and environmental optimum estimates could be made for all cultivars in cropping systems with varying levels of inputs (fertilisers, fungicides and straw shorteners) and for different wheat-price scenarios. More comprehensive information about the advantages of resistant cultivars could also be diffused.

Thirdly, the promotion of hardy multi-resistant cultivars should ideally go hand-in-hand with efforts to promote wheat production systems less prone to fungal diseases. Various non-breeding strategies, such as spatio-temporal alternation or cultivar mixtures, can improve the durability of the genetic control of pathogen populations (Mundt, 2002, Cox et al., 2004, Vallavieille-Pope, 2004). It has been shown that these strategies receive insufficient attention in agricultural research systems (Vanloqueren and Baret, submitted for publication). Both research and development, and agricultural policies should take these strategies fully into account and promote them (Diamand, 2003).

Besides using 'positive' methods to promote these preventive strategies, public authorities can also use 'negative' methods to reduce the use of pesticides. Tighter pesticide regulations and a dissuasive tax on pesticide use are two of the main tools that have been used by countries, such as Denmark, which have implemented national pesticide—use reduction plans sooner than Belgium and France (Aubertot et al., 2005).

5. Conclusion

The failure of disease-resistant wheat cultivars to become a mainstream cultivar choice in wheat production is not due to poor technical characteristics such as low yield or poor bread-making quality. Factors impeding the development of resistant cultivars exist at all levels of the food chain, from farmers to input suppliers to CAP policies. Even extension services do not fully support the use of disease-resistant cultivars in low-input systems, despite their recent economic successes. This paper has shown that modern wheat systems are in a locked-in situation favouring the use of high inputs (fertilisers, chemical pesticides and straw shorteners). The development of hardy multi-resistant cultivars and profitable low-input systems will require not only improved cultivars but also planned efforts.

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