D4.2 Report describing three crop case studies investigating in detail the socio-economic factors influencing the behaviour of various stakeholders regarding the use of organic seed

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Authors	Stefano Orsini, Francesco Solfanelli, Eva Winter, Susanne Padel, Emel Ozturk

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Summary

This report explores common aspects and differences in relation to organic seed in arable, horticulture and forage crop sectors. It builds on literature, an analysis of the status quo and regulatory regime for the different sectors, and interviews with stakeholders of a number of seed supply chains in different countries. In total 68 interviews were carried out with experts in organic seed production across Europe, in the following countries: Bulgaria, Denmark, France, Germany, Greece, Hungary, Italy, Lithuania, Netherlands, Poland, Portugal, Romania, Spain, Switzerland, United Kingdom. In addition to the overview of the crop sectors, a more detailed analysis has been carried out for three selected crops within each sector (focus crops): durum wheat, bread wheat and lupine for arable crops; carrot, cauliflower and apple for horticultural crops and lucerne (syn. alfalfa), perennial ryegrass and white clover for forage crops.

The three sectors have in common that they are characterised by substantial increase in the organic land area in the last decade, leading to increased demand for organic seed. However, despite the attempt to gradually phase out the use of untreated conventional seed under the derogation regime, untreated conventional seed is still commonly used for most crops and in all European regions, although some differences can be observed. Non-organic seed use is highest for some forage crops and in the South and East of Europe, whereas for cereals and vegetables in Central Europe non-organic seed use is estimated to be below 25%. Amongst the focus crops, experts estimated that for carrots about 90% of the seed used are conventionally multiplied (from conventionally bred cultivars).

Overall it seems questionable whether the derogation regime alone is sufficient to achieve lasting improvements to organic seed use in Europe. The comparison of derogations between 2004 and 2014 to 2016 for selected crops has shown that the volume of seed and number of derogations have increased in most cases. This goes alongside a substantial increase in land area, which is likely to continue (as several countries have growth targets for organic agriculture) and lead to additional demand for organic seed.

Most of the production of organic seed and propagation material for arable and horticulture occurs in Central Europe. In South Europe, micro-initiatives exist for organic seed production in both sectors, although they provide a small share of the organic seed requirement in Europe.

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Organic seed production for forage crops mainly occurs in Central and Northern Europe, with the only exception of lucerne which is multiplied for organic seed production mostly in Italy and France. In contrast to the other crop sectors, where examples of interaction and integration between the seed multiplication stage and the market actors of the whole food chain (such as processors and retailers) were identified, in the forage sector interaction in the supply chain appear to occur only between seed companies and farmers.

In general, organic wheat seed is more expensive to produce than conventional. Lower yields can occur due to both weed and disease impacts, and as a result the price difference between conventional and organic seed is pronounced.

Carrot is a technically particularly challenging seed crop with pest and disease risk for which not enough organic alternative treatments have been developed. For cauliflower, organic multiplication seems less challenging, as it can be done in greenhouses and poly tunnels.

Apple transplant production is challenging too and investment in pest and disease management under organic conditions at rootstock, scion and transplant level are needed if the availability of good quality organic propagation material for apples has to increase.

A specific challenge to increase the use of organic seed is related to forage crops that are grown in mixtures which, particularly in organic farming, they have to be as much diversified as possible with diverse species and varieties. This makes it difficult to find organic seed for all the crop species and varieties needed. For such reasons, the seed companies argued that adopting a 70% threshold rather than the more stringent 100% rule for the mixture would be preferred, allowing more room for manoeuvre in adjusting and tailoring the mix to the needs of organic farms.

In the arable seed sector, organic breeders are unanimous about the need to develop specific breeding programs for organic durum and soft wheat. However, these are limited by two main factors. Firstly, there is low return on investment in dedicated organic breeding programmes, which is strongly related to the small size of the organic market. Secondly, there is a lack of organic VCU procedures that include variety testing under organic conditions. These exist only in a few EU countries and mainly for soft wheat. Unlike wheat, there are not substantial differences in breeding goals between conventional and organic lupine. The narrow base of genetic diversity is the main limit faced by both conventional and organic breeders. Overall, we observed that there is an increasing number of Participatory Plant Breeding projects for organic cereals in Europe, which however represent only a minor part of the total European organic seed requirement.

The global trend of concentration in vegetable breeding results in companies investing mainly in the breeding of crops that are expected to be profitable. Actors working with these companies see no need for special breeding activities for organic farming. In contrast, there are a number of mainly smaller companies and/or initiatives involving farmers, which work with a wider range of crops and mostly with open pollinated cultivars for organic. Breeding activities exclusively for the organic sector by private companies have partly developed in response to dominance of cultivars bred with cell fusion in the conventional market making breeding techniques a major point of departure.

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From the interviews it emerged there seems to be no agreement among experts and companies as to whether organic and conventional breeding programmes for fruit and vegetables have the same or substantially different breeding goals. Also, most existing breeding initiatives for organic cauliflower, carrot and apple production have fragmented and insecure funding. Like in the arable sector, the stakeholders interviewed agreed that with the current organic market size, organic breeding activities cannot be entirely re-financed through seed sales. However, a few cases illustrated in this report of public-private cooperation as well as value chain-based pre-financing model provide some successful examples of organic breeding.

Breeding for organic farming conditions is far less developed in forage than in the other crop sectors. The only breeding programmes for both ryegrass and clover is undertaken by Agroscope in Switzerland, which works in a public private partnership. This is also the most common financing model for conventional breeding for this sector. The stakeholders interviewed argued that there is not a specific need for breeding for organic forage crops, as the goals are similar, i.e. improved nitrogen efficiency use in grasses, crop persistency, resistance to biotic and abiotic stress and overall forage quality. The conclusion according to the stakeholder consultation undertaken in our study is that in the forage sector it should be possible to breed in conventional way for organic farming considering the specific goals. However, more empirical evidence is needed by testing varieties bred in conventional and organic in mixtures (rather than pure stand) under a wide range of management systems.

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1 Introduction

The new European Organic Regulation (EC/2018/848) sets out a number of objectives, including phasing out derogations allowing the use of untreated conventional seed by 2036, and fostering the development of breeding programmes for the organic sector.

The requirement to use seed and vegetative propagation material that is multiplied under the conditions of organic farming applies to all crops grown in organic agriculture, regardless of how much of that crop is grown. Taking all major and minor crops into account, the number of species for which an organic seed multiplication regime needs to be developed is considerable. For many crops also subspecies and crop type groups need to be considered (e.g. carrots for processing and carrots for the fresh market, cherry tomatoes versus tomatoes for processing). The new regulation also emphasises the need for genetic diversity and to develop breeding programmes for the organic sector, which should, ideally, also apply to all these crops.

There is a need to understand the state of organic seed and breeding in Europe from the point of view of different stakeholders as well as from secondary sources, taking into account the different sectors of combinable arable crops (cereals and pulses and oilseeds), horticultural crops (vegetables and fruit) and forage crops (e.g. clovers and grasses). These cropping sectors differ in the challenges they face regarding organic seed multiplication in terms of the number of species used, the availability of alternative cultivars and varieties including those less widely grown and those bred and developed specifically for organic agriculture, variety trials under organic conditions, technical issues in seed multiplication, regulatory differences in the seed regulation, the importance of farm-saved seed, and the importance of local, national and international seed markets for specific species and sectors. The sectors also vary in the existence and objectives of organic breeding programmes and different farmer-driven, commercial or community business models in specific seed supply chains. All this implies that what can be learned from one species (e.g. winter wheat, carrots) in one country cannot necessarily be generalised to the organic seed sector as a whole.

This report explores the common aspects and differences in relation to organic seed in arable, horticulture and forage crops. It builds on literature, an analysis of the status quo and regulatory regime for the different sectors and selected species, and interviews with stakeholders of a number of seed supply chains in different countries.

We adopted a case study approach, focusing on the three specific sectors each as a case but also considered in more detail selected crops within each sector. The selection of crops was driven by data availability, the existence of different forms of market interactions, the choice of cultivars, reliance on organic multiplication of conventionally bred cultivars and the number of derogations. This detailed focus allowed us to move beyond general statements and try to better understand different socio-economic and technical factors that may foster or limit the growth of the organic seed sector and the development of breeding programmes dedicated to specific organic crops.

This report is structured as follows. The next section illustrates the approach employed. The trend in organic land area for the crop sectors and the specific crops chosen is reported together with the derogation trend and the regulatory issues specific for each sector. Results from the interviews on seed multiplication and breeding are presented together with relevant literature confirming (or not) and complementing what stakeholders reported. Some conclusions close the report.

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2 Approach

The research presented here adopted a case study approach. Case study research according to Yin (2014) is a linear but iterative process in the social sciences, dealing mainly with "how?" and "why?" questions in settings where the researcher has little control over aspects of "the case" in the real-world context. Embedded case studies can involve more than one object of analysis and use both mainly qualitative but also quantitative methods, and subunits can focus on different aspects of the case (Scholz and Titje, 2002). The conceptual basis for the case studies is the value chain framework, consisting of the mapping of key actors from the breeder to the consumer of the end product.

Our three cases are value chains for the use of organic seed or vegetative propagation material and the functioning of supply chains for combined arable crops (i.e. cereals and pulses), horticulture (i.e. vegetables and fruit) and forage crops (i.e. legumes and grasses).

The case study research consisted of three interrelated steps:

(i) Review of various sources of information to establish general trends for each crop sector;
(ii) Selection of three specific focus crops in each sector and
(iii) Expert interviews with LIVESEED project partners, stakeholders experienced in the three sectors and with persons working in companies that have activities in relation to the focus crops.

The analysis of the cases aims to describe the situation, identify interactions between key actors, established technical, regulatory and market challenges and typical business models and explore the enabling environment. We paid particular attention to the difference and commonalities between the different sectors, the different focus crops and different regions of Europe.

2.1 Trends of organic seed use in the three sectors

The following materials were consulted to get an overview of the general trends of organic seed use for three case studies of crop categories:

- Statistical sources from Eurostat and FiBL statistics (Willer and Lernoud 2019) regarding the area under organic cultivation
- Scientific and grey literature on organic seed use and breeding, based on search of scopus related to organic seed and breeding (see Orsini et al., 2019 D4.1 for details) and sources identified by LIVESEED partners.
- Reports on the status quo of derogations of LIVEED (see Solfanelli et al., 2019)
- Results of the LIVESEED survey of 839 organic farmers in 17 European countries in relation to enabling factors of seed used (see Orsini et al., 2019 D 4.1 for details).
- Examples of good practice for an improved implementation of the organic seed regime identified in the national visits (Raaijmakers and Schäfer, 2019)

Both Solfanelli et al. (2019) and Orsini et al. (2019) grouped the countries in four regions of Europe.

- **Eastern EU** (BG, CZ, HU, PL, RO, SK);
- **Central EU & Switzerland** (AT, BE, FR, DE, LU, NL, CH);
- **Northern EU** (DK, EE, FI, IE, LV, LT, SE, UK) and
- **Southern EU (**HR, CY, EL, IT, MT, PT, SI, ES).

The results of the review of trends in the three sectors are presented in Chapter 3.

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2.2 Selection of focus crops for each sector

Within each cropping sector we selected three specific focus crops that allowed us to consider different aspects that are of varying importance for the different crops in more depth, considering also quantitative data that do not exist at sector level (Table 1).

The selection of focus crops considered the following criteria:

- The relevance of the crops in terms of the land area used in Europe,
- Information on derogations and in the literature,
- Expertise and experience about the crop among LIVESEED partners and stakeholders in different countries,
- Geographical coverage (North/Southern/Eastern Europe),
- Crop types within the crop sector – i.e. grass and clover crops, vegetable and fruit crops, cereals and pulses,
- Financing strategies for breeding.

The selected crops are described in more detail in Chapter 3 of this report.

Table 1: Selected focus crops in each crop case study

Crop sector	Focus crop species
Combinable arable (lead: UNIVPM)	Soft wheat (*Triticum aestivum*)
	Durum wheat (*Triticum durum*)
	Lupine (*Lupinus albus*)
Vegetable / Fruit (lead: FiBL-CH)	**Carrot (*Daucus carota*)**
	Apple (*Malus domestica*)
	Cauliflower (*Brassica oleracea var. botrytis*)
Forage (lead: ORC)	Alfalfa (*Medicago sativa*)
	White clover (*Trifolium repens*)
	Perennial ryegrass (*Lolium perenne*)

Crops in bold will be modelled in Task 4.2.2 in a specific country context (see Winter, 2019).

A number of factors were identified that are likely to be of varying importance for each crop. These include

- The importance of local and/or organically bred varieties
- The use of local and/or international markets for seed
- The importance of farm saved seed
- Farmer-driven, commercial and community-based seed business models and
- Structure and functioning of end product supply chains and successful/ failing examples

The presentation of each of these supply chain cases includes a description of supply chain structure and business practices in the respective crop markets. The following crop-country combinations have been

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selected for the modelling in task 4.2.2: Organic carrot production in Germany, organic ryegrass production in the UK and organic durum wheat production in Italy (See Winter 2019 for details).

For each sector case study a small stakeholder advisory group of project partners (including business partners of the consortium) was established that met during the annual project meetings and supported the case study work, for example the selection of focus crops, the identification of important actors and description of prevalent business models in the sector and carry out a SWOT analysis of the sector.

2.3 Expert interviews

In total 68 interviews were carried out with experts in organic seed production, both from within the LIVESEED project consortium and with person from the stakeholder network from companies working with organic seed multiplication, trade or breeding of organic crops in the three sectors, including with the specific focus crops (Table 2). The interviews were carried out in two steps.

The first step was aimed at getting a general overview of the organic seed production and breeding for each sector. Experts in different countries were chosen from the LIVESEED project partners. The interview guide covered questions related to general functioning of the organic seed market in the specific sector, and specific technical and regulatory challenges encountered and helped to identify further experts from seed companies to be interviewed in the second stage.

In the second step, organic seed producers and/or breeders were contacted either by the project partner responsible for the case study or the national LIVESEED project partner. Some of those companies are also project partners but are listed here as companies because that was the main reason why we interviewed them.

The interview guide included questions about the company, the crops and activities that the company engaged with, experiences with organic seed multiplication, with the seed market with organic breeding. The interviews also contained questions about differences in the market and the costs of organic seed multiplication and breeding that will be considered in the modelling in Task 4.2.2.

Table 2: Number of expert interviews conducted

Crop sector	With project partners	Companies			Total	Countries
		Mixed focus	Focus on seed multiplication	Focus on Breeding		
Arable	9	18	1	1	29	10
Horticulture	8	13		3	24	12
Forage	5	3	7	0	15	7
Total	22	34	8	4	68	15

Interviews were carried out in the following countries:

- For combinable arable crops in Denmark, France, Germany, Greece, Hungary, Italy, Poland, Romania, Spain and the UK.
- For horticulture in Bulgaria, Denmark, France, Germany, Greece, Hungary, Italy, Netherlands, Portugal, Romania, Spain and Switzerland.
- For forage crops in Denmark, Germany, Italy, Lithuania, Romania, Switzerland and the United Kingdom.

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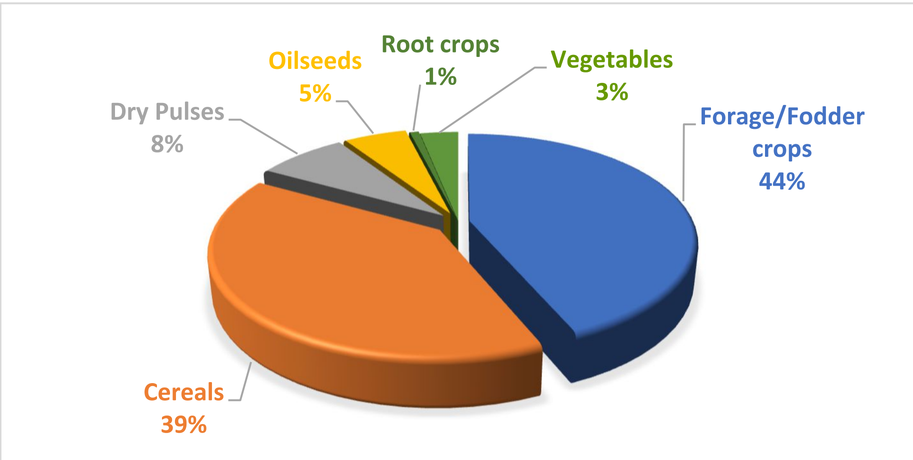
In total, the study interviewed experts in fifteen countries, of which three were the region North-West (Denmark, Lithuania and the UK), four in Central Europe (France, Germany, Netherlands and Switzerland), three Member states in the South (Italy, Spain, Portugal) and five in Eastern Member states (in Bulgaria, Greece, Hungary, Poland, Romania).

3 Trends in organic cropping and organic seed use

The crop categories covered in the case studies are grown on arable land, permanent pasture and permanent crops. Organic arable land reached 5.5 million ha in 2017, which represent 43% of the total organic land in the EU. The area for organic arable crops almost doubled in the period between 2008 and 2017, with an annual increase of approximately 6% between 2016 and 2017. By country, the largest arable cropping land is in France (0.9 million ha), followed by Italy (0.8 million ha), Germany (0.5 million ha) and Spain (0.5 million ha).

The selected crop sectors account for a large proportion of organic arable land in the EU (Figure 1). The largest share (2.1 million hectares in 2017) is used to grow forage and green fodder crops, including temporary grasslands and other small seeded legumes (e.g. lucerne). Cereals represent the second most important cropping category by area (1.9 million ha in 2017), followed by dry pulses (0.4 million ha) and oilseeds (0.27 million ha) (Willer and Lernoud, 2019).

Figure 1: Organic arable land use and key crop group in 2017



Source: Willer and Lernoud (2019)

In terms of regulatory issues, 6 EU Member States (Belgium, Netherlands, Luxembourg, France Germany and Sweden) and Switzerland have developed National Annexes to the organic regulation, listing crops for which derogations for the use of non-organic seed are no longer granted (Category 1) and crops that fall under a general derogation (Category 3).The crops of each crop sector that belong into these Categories are listed in the following sections. All other crops in these countries and crops in all the other countries require an individual derogation if the producers want to use non-organic seed.

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3.1 Combinable arable crops (cereals, pulses and oilseeds)

3.1.1 General trends

Cereals are the most important organic combinable arable crop group with 1.9 million ha in 2017, representing about 35% of all EU organic cropping land and about 3.5% of the total EU cereal area. The species include soft and durum wheat, spelt, barley, oats, grain maize, rye and triticale as well as rice and Andean grains, which are less important in Europe. The organic cereal area in the EU increased by 50% between 2008 and 2017, and by 6% between 2016 and 2017.

In 2017, organic dry pulses accounted for 0.39 million ha in the EU and for about 18.1% of all area growing dry pulses in the EU. The species include pea, fava bean, lupine, lentil, bean, grasspea, chickpea and others. This indicates the importance of these crops for organic agriculture, but also the prominence of the organic sector for growing pulse crops as animal protein feed crops in the EU. The area of organic pulses increased by more than 200% between 2008 and 2017, but only by 1% between 2016 and 2017.

Organic oilseeds crops account for 0.27 million ha and represent a share of 2.3% of the total oilseed area in the EU (Willer and Lernoud, 2019). The species include among others sunflower, oilseed rape (canola), soybean and camelina.

3.1.2 Organic seed use, derogations and regulatory issues

The combinable arable crops that have been included in the six National Lists in Category 1, where sufficient organic seed is available, are shown in **Error! Reference source not found.**. The most frequently listed crops are oat and grain maize, both listed in five countries, followed by soft wheat, spelt, triticale, and rye. Several other grains are listed in three or two countries. Blue lupine is listed in two countries, but no other lupine species is listed; and fava beans and peas are each listed in one country. Durum wheat which is an important crop in Southern and Eastern countries is not listed in these six countries (**Error! Reference source not found.Error! Reference source not found.**. The number of derogations granted increased for several cereals between 2014 and 2016, which is partly explained by the increase in land area in the same period (Table 4).

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Table 3: Cereals, pulses and oilseed crops in Category 1 (no derogations) in countries that have national Annexes in 2019

Crops	Belgium	Germany	France	Luxemburg	Netherlands	Sweden	Switzerland
Barley					✔	✔	✔
Grain maize		✔	✔	✔	✔		✔
Oat		✔*		✔*	✔	✔	✔
Rye		✔**		✔**	✔		✔
Soft wheat			✔		✔	✔	✔
Soya bean							✔
Spelt	✔		✔		✔		✔
Triticale	✔		✔		✔		✔
Blue lupine		✔		✔			
Fava beans						✔	
Field pea						✔	

* Only summer oat is listed, ** Only winter rye is listed

Table 4: Evolution of granted derogations (volume of seed) compared to the development of organic areas (ha) in EU Member States and Switzerland, 2014-2016

Crops	Increase in organic land area	Increase/decrease in granted derogations (percentage of volume of seed)
Wheat	+ 39%	+ 55%
Barley	+ 19%	+ 20%
Grain maize	+ 12%	- 7%
Oats	+ 25%	+ 28%
Lupine	+ 13%	+ 115%
Soybean	+ 58%	+ 84%

Figure 2 and 3 below show the number and volume of derogations per thousand hectares for barley, grain maize, soybean and wheat in 2004 in comparison with the period from 2014 to 2016. The results demonstrate that many more derogations were granted for barley and wheat, while the number of derogations for soybean remained constant over the years. The situation is similar for barley and wheat when looking at the volume of seed granted through derogation, while for soybean the volume seed for which derogation was granted shows a considerable increase over the years. The data on the number and volume of derogations are influenced by the country specific average farm type. They can therefore not be considered as a good indicator for the dependence on non-organic seed. Also, one

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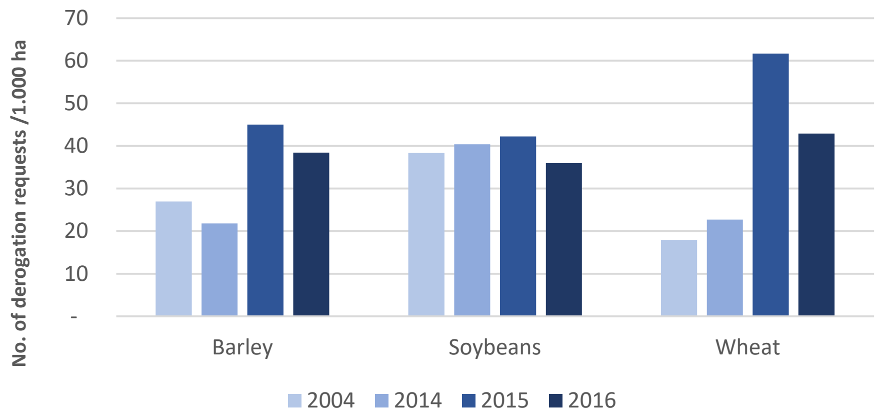
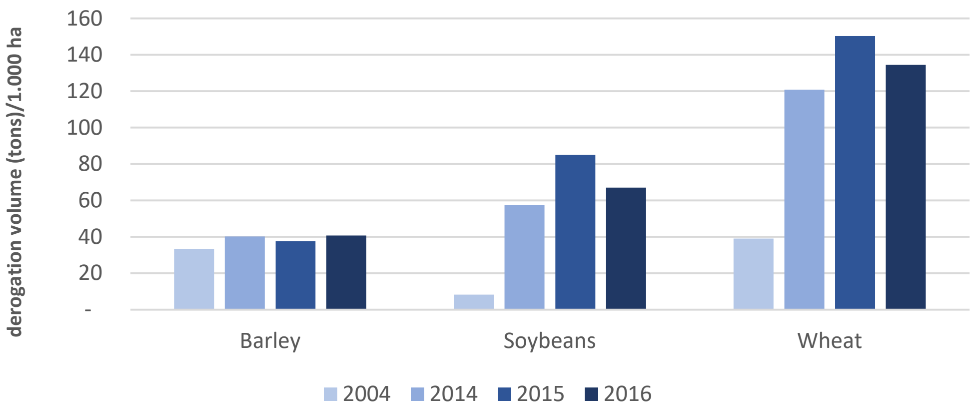
should consider that in the last few years soft wheat and barley were placed in Category 1 list in in some EU Member States (see for more details Error! Reference source not found.).

Figure 2: Number of derogations per 1.000 hectares of organic barley, soybean and wheat land over years



Source: Solfanelli et al., 2019; Thommen et al., 2007.

Figure 3: Volume of derogations per 1.000 hectares of organic barley, soybean and wheat land over years



Source: Solfanelli et al., 2019; Thommen et al., 2007.

In two Baltic States, the governments use additional payments in the Rural Development Program (RDP) scheme for organic seed issues. The Estonian government supports the use of certified organic seeds for cereals with a 20% higher support under RDP measure for the area organic seeds are used. In Lithuania, the production of organic seed is supported with additional payment under the RDP. For cereal seed production an additional endorsement of €273 per hectare is paid. Latvia offers subsidies for seed production – organic and conventional – with a minimum production per hectare.

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Organic variety trials for arable crops are currently carried out in 13 EU Member States (**Error! Reference source not found.**, based on Kovács and Pedersen, 2019). The trials are mostly performed with soft wheat (spring and winter), with durum wheat variety trials having been set up in Italy and Greece. Lupine is tested in Austria, Germany, and Poland. The funding for cultivar trials varies among countries. Some institutes have a funding from the government, breeders and seed companies pay the costs of running the trials in some countries and others mostly use project funds. Dissemination of results is mostly organized by researchers who are also coordinators of the trials. France (for cereals), Italy, Switzerland, and Germany have official recommendation list of varieties for organic farmers.

Table 5: Organic variety trials and VCU or supplementary organic registration trials in Europe

Crops	Austria	Denmark	France	Germany	Greece	Hungary	Italy	Latvia	Netherlands	Poland	Romania	Switzerland	UK
Variety trials													
Durum wheat					✔		✔						
Soft wheat	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Lupine	✔			✔						✔			
VCU or supplementary registration trials													
Soft wheat	✔	✔	✔*	✔				✔					

* Only supplementary organic registration trials

Source: Kovács & Pedersen (2019)

During cultivar registration and mandatory prior cultivar testing in the EU, different benchmarks are of relevance depending on the crop type. There are the Value for Cultivation and Use (VCU) and distinctiveness, uniformity, stability (DUS) criteria. For vegetable and fruits, only the DUS criteria are of relevance. For arable crops, also thresholds of VCU need to be reached before a cultivar can be released and seed are marketed. Here, for example aspects such as that the new cultivar has a higher yield and protein content than already existing cultivars are evaluated (Page 5 of Kovács and Pedersen, 2019 -> this is the cultivar testing deliverable in LIVESEED).

Organic VCU or supplementary organic registration trials (organic variety testing under VCU conventional trials supplemented with organic trials) are currently running in France, Austria, Latvia, Denmark and Germany (**Error! Reference source not found.**) only for soft wheat. The absence of official organic VCU testing in other countries is explained in the interviews with a low organic market share and no requests for official registration of organic varieties. Organic breeding does not exist in these countries or there is lack of financial resources to carry out such activities.

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The new Organic Regulation (EU 2018/848), coming into force in January 2021, recognizes the Organic Heterogeneous Material (OHM) as a new category of plant reproductive material which can be marketed and used by organic farmers. Nevertheless, regarding the production and marketing of

heterogeneous material, the new organic regulation is less restrictive than the temporary experiment currently implemented by the commission in term of type of crop species, breeding selection methods, seed quantity per crop and country (see Commission Implementing Decision EU 2014/150). After 2021 seed of OHM can be commercialized with notification but without the need for DUS or VCU testing or official seed certification. The major requirements are that production of OHM should be in accordance with the organic regulation. Given the importance of the heterogeneous plant populations for the organic farming systems, the extension of the Temporary Experiment will bridge the ongoing population marketing experiences with the provisions of the new Organic Regulation. According to Costanzo et al. (2018), a total of 35 populations have been authorized by the member states included in the temporary experiment in 2018. The largest volume of seed from heterogeneous population sold in the Member States was organic, as many of the research institutes and seed suppliers involved in the temporary experiments are organic or biodynamic (e.g. 2 populations of winter wheat were registered by UBIOS in France, 7 from F&Z Dottenfelderhof in Germany, 3 from Arcoiris /RSR in Italy and 1 from ORC in UK.).

3.1.3 Focus crops

Within the arable crop sector, two cereal crops (soft wheat and durum wheat) and one pulse crop (lupine) have been chosen for the case studies. The aim of this selection is to understand how and if market, supply chain and technical issues differ between cereals and pulses in relation to organic seed use, production and breeding.

Soft wheat (Triticum aestivum) and durum wheat (Triticum durum)

Wheat was chosen as focus crops in the case study since they are the key cereals produced in the European organic sector with the largest production areas (600.000 ha and 250.000 ha total production area in 2016, respectively). Currently, soft wheat is included in the Category 1 list in France, Netherlands, Sweden, and Switzerland, but also listed as Category 3 for different subspecies (winter, summer) in five countries. Durum wheat is in the Category 3 in Belgium, Latvia, Sweden, and Switzerland, where durum cultivation is of minor importance due to climatic reasons.

Derogations are granted in most of the producer countries. Indeed, there has been a strong increase in derogations for untreated conventional seed during the period 2014-2016, which is also related with the increase in the area of these two crops (Figure 4).

Some successful initiatives of the organic seed value chain of wheat have already been identified in some countries -such as Italy, France, and Germany. These are considered in the case study to understand key success factors. The modelling of organic seed value chains in Task 4.2.2 will focus on the crop- country case of durum wheat in Italy.

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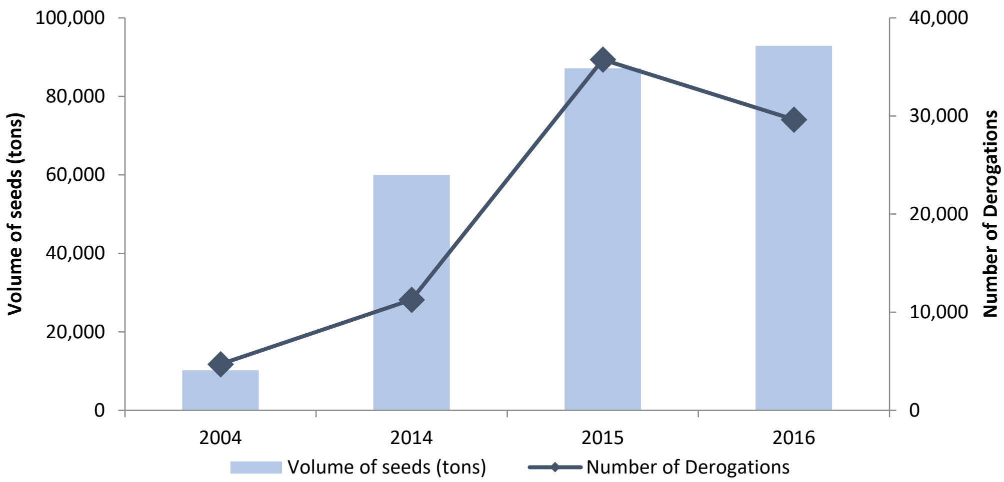
Figure 4: Volume of authorized seeds and the number of derogations for non-organic seed of wheat (soft and durum) in 2004 and 2014-2016



Source: Solfanelli et at (2019) and Thommen et al. (2007)

Lupine (Lupinus spp.)

Lupine was chosen as a third cereal crop for the case study. Lupine has potential as a high-protein human and animal feed crop and thus as an alternative to imported soybean meal in organic livestock. So far, the main barrier to further increase the production of lupine seems to be linked with a relatively low yield and scarce tolerance to anthracnosis diseases, largely due to limited breeding researches (Lucas et al., 2015).

In the past years, problem of anthracnose disease in white lupine (*Lupinus albus*) shifted the attention of the European lupine production sector almost exclusively on blue lupines (*Lupinus angustifolius*). Despite this, white lupine is generally characterized by a higher yield, higher protein content and higher competitiveness against weeds. Blue lupine has a shorter production cycle, which allows this crop to be growth with good performance also further north. Blue lupine is cultivated mainly in Germany, Poland and Switzerland, while white lupine is cultivated in France and in the Mediterranean countries (Italy and Greece).

The use of organic seed for lupine varies across EU Member States (e.g. 90% in France; 77% in Germany, but lower than 5% in Italy, Spain and Czech Republic). Only blue lupine is listed as Category 1 in two countries, in Germany and Luxemburg. Because of limited production of organic lupine seed, blue lupin is listed at Category 3 in Finland. Other subspecies of lupine were listed in Category 3 lists of seven countries, with lists being updated annually.

The case study aims to identify the current developments as well as bottlenecks that should be solved under organic farming conditions for this focus crop.

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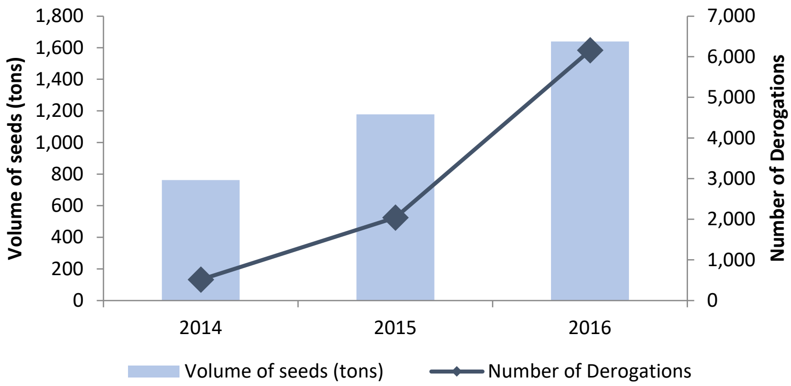
Figure 5 summarizes the overall development of derogations for lupine in the EU and Switzerland. The total volume of authorized non-organic lupine seed increased by 115% from 2014 to 2016, data for 2004 are not available for this crop. This data reflects the strong and continuous development of organic lupine production area -particularly in Germany, Poland, and France.

Figure 5: Volume of authorized seeds and the number of derogations for lupine from 2014 to 2016



Source: Solfanelli et at (2019) and Thommen et al. (2007)

3.2 Horticultural crops

3.2.1 General trends

In the following, a closer look is taken at the organic fruit and vegetable sector. Temperate fruits take up 204,382 ha of the organic area world-wide. There was a slight decrease of this area between 2016 and 2017. 134,038 hectare or more than half, is found in Europe (101 476 ha in the EU), showing the importance of this crop group for Europe. 4.8 % of all the temperate fruit area and 4.1% of fruit producers are organic, mostly located in Italy, Spain, and Poland (Willer and Lernoud, 2019).

The organic vegetable area world-wide in 2017 was 675,980 ha, of which 172,792 ha was in Europe and 158,929 ha in the EU, indicating the importance of this sector in Europe. The vegetable area in the EU has increased by 69% between 2008 and 2017, and by 17% between 2016 and 2019. Globally, the organic vegetable area increase more than six-fold, between 2004 and 2017; large increase of organic vegetable area were observed in China and in Italy, and Spain (Willer and Lernoud, 2019).

Some countries with large organic vegetable production are for example Germany with 13,846 ha, Spain with 20,331, and Italy with around 40,000 ha. One of the countries with a high share of organic vegetable production of the whole vegetable production is e.g. Denmark (30%), although it is only an area of around 3,000 ha of organic vegetable in Denmark, so overall a small area (Lernoud et al. 2019).

3.2.2 Organic seed use, derogations and regulatory issues

Organic fruit and vegetable seed value chains are diverse as regards organic seed and cultivar choice. There is evidence that the down-stream part of the value chain seems to have a strong impact on farmers' seed choice. Longer supply chains, so including intermediaries, processors, and supermarkets, affected organic vegetable seed use negatively. Further, more specialised organic vegetable farmers

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also tended to use less organic seed. Other aspects, such as education and the use of known cultivars also strongly influence if organic seed is used in vegetable production or not (Rey *et al.*, 2013; Levert, 2014; Le Doaré, 2017).

According to the survey conducted by the Organic Seed Alliance, vegetables lag behind other crops in the US with only 18% of vegetable growers planting 100% organic seed, compared with against 30% of field crops, forage crops, and cover crops (Hubbard and Zystro, 2016). Rey et al. (2013) and more recently Le Doaré (2017) found that organic vegetables growers in France and Britany respectively tend to use more non-organic seed if they operate in long food supply chains compared to growers in short supply chains. Farmers growing vegetables for processing and in greenhouses tend also to use conventional seed, which was attributed to them looking for high productivity and capability to meet the requirements of long food supply chain, such as presentation and shelf-life (Rey et al., 2013; Levert, 2014; Le Doaré, 2017).

The new EU regulation for organic production (EC 848/2018) aims to phasing out derogations for non-organic seed use in organic production. However, currently only seven countries have included vegetable species or subspecies in Category 1, which means that only organic seed can be used (Table 6).

Table 6 shows that the Netherlands have by far the most extensive list of vegetable crops in Category 1. This is an indication of the vegetable seed companies producing organic seed, which makes the decision to enlist a crop possible. A few other countries have about half the number of vegetable crops enlisted, namely France with 13, Belgium with 12 and Germany and Luxemburg with 9 vegetable species. Switzerland and Sweden have only two vegetable species listed. The countries with the most crops in Category 1 are geographically close to each other. It is likely that they can rely on the same cultivars that are available as organically multiplied. For example, we compared the cultivars used for onion in four countries that use the OrganicXseeds database (Belgium, Germany, Luxemburg, Switzerland). The same sub-species (e.g. summer onion for sowing) are listed in Category 1 and mostly the same cultivars from German and Dutch seed companies are offered, several of them are organic cultivars.

In the interviews, two examples how the competent authorities in different countries try to stimulate more organic seed use in order to pave the way to place some species in Category 1 were highlighted:

- Agreeing on a percentage of organic seed that needs to be used for a certain species or sub-species (Interview evidence from France and Denmark)
- Making it mandatory to all applicants for derogation to pay the difference between the organic and the conventional seed price. This method is applied in Switzerland for e.g. potatoes and fruit tree transplants (Bioaktuell, 2019). However, this may not be in line with European regulations against market distortions, as was outlined for the case in France (interview evidence from France).

The change in the number of derogations granted between 2014 and 2016 is shown in Table 7.

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Table 6: Vegetable crops in Category 1 (no derogations) in countries that have national Annexes for seed crops in 2019

	Belgium	Germany	France	Luxemburg	Netherlands	Sweden	Switzerland
Onions	✔	✔	✔	✔	✔		✔
Shallot					✔		
Celery	✔		✔		✔		
Cucumber	✔	✔	✔	✔	✔		
Swiss chard	✔				✔		
Chicory					✔		
Pumpkin	✔	✔	✔	✔	✔		
Squash			✔		✔		
Beans		✔	✔	✔	✔	✔	
Soy beans							✔
Peas					✔	✔	
Potatoes		✔		✔	✔		
Turnip					✔		
Lettuce			✔		✔		
Tomatoes					✔		
Strawberries					✔		
Red beetroot	✔				✔		
Cabbage	✔						
Cress	✔	✔		✔	✔		
Endive	✔	✔	✔	✔	✔		
Purslane	✔				✔		
Radish	✔	✔	✔	✔	✔		
Carrot			✔				
Eggplant			✔				
Fennel			✔		✔		
Gherkin			✔		✔		
Fresh pea					✔		
Sugar pea					✔		
Garlic					✔		
Kohlrabi	✔				✔		
Sweet pepper		✔		✔	✔		

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Different sub-species of the same crop can be listed Category 1 as well as in Category 3.

Table 7: Non-organic seed granted through derogations (volume of seed) for organic vegetable crops in EU Member States and Switzerland from 2014 to 2016 *

Crop	Increase/decrease of granted derogation (%) (percentage of volume of seed)
Carrots	+ 96%
Cauliflower	+ 52%
Onion	+ 28%
Potatoes	+ 285%
Broccoli	+ 70%
Melon	- 50%
Cucumber	- 68%
Chicory (endives)	- 15%
Endives	- 47%
Lettuces	+ 426%
Tomatoes	+ 275%
Pumpkin	+ 132%
Parsley	- 57%

*Data on land area were not available at the time of writing this report

As mentioned in the section of combinable arable crops, organic cultivar trials are necessary also to show organic farmers which cultivars are most suited. Organic cultivar trials for vegetables have been set up in the following countries: France, Germany, Switzerland and Spain. Various vegetables are tested, although the main focus is on tomato. This is due to the economic importance of tomato in the vegetable sector world-wide. Often, these trials rely on fragmented and project-based funding. Mostly open-pollinated cultivars or land races are tested, which are the minority in organic vegetable production and only available to a limited extent. Organic cultivar testing based on stable funding, a wider range of organically multiplied species and cultivars, together with a sound communication strategy are recommended to fully exploit its potentials (Kovács and Pedersen, 2019).

Organic cultivar trials for fruit have been set up in the following countries: Greece, Switzerland, France, Poland, and Denmark. They focus on pomaceous fruits. The funding for fruit cultivar trials is more diversified than for vegetables. Some institutes have a secure funding from the government, others rely on project funds. There is more frequent communication of trial results for fruits to farmers. In Switzerland, the leading institution has managed to build up a network of stakeholders to identify the most relevant characteristics for testing (Kovács and Pedersen, 2019).

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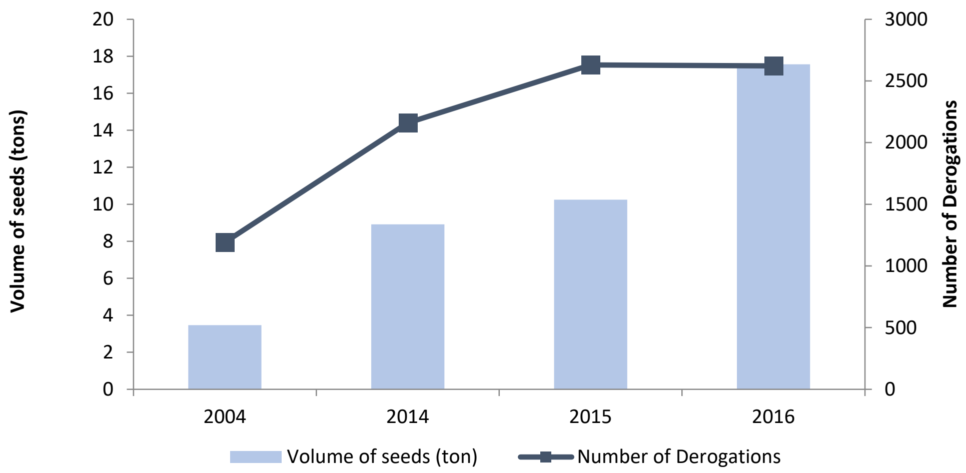
3.2.3 Focus crops

Two vegetable crops (carrot and cauliflower) and one fruit crop (apple) were selected. All focus crops are grown in many European countries. Seed production for carrot and cauliflower (both biennial) plants is particularly challenging from a technical point of view.

Carrot (Daucus carota)

There has been a considerable increase in the number of derogations in Europe between 2014 and 2016 (by 55%). The regulatory situation of carrots is varied, making it an interesting crop for the case study and the modelling (Task 4.2.2), looking at availability of organic seed, national application of the regulation, and technical and pedo-climatic conditions. Only in one country (France) carrot is placed in Category 1, which is further described in Section 5.2.2. Seven out of the 12 countries with National Annexes placed carrot in Category 3 requiring no derogations at present (Solfanelli *et al.* (2019). The development of derogations for untreated conventional seed for carrots is shown in Figure 6.

Figure 6: Volume of authorized seeds and the number of derogations for carrots between 2004 and 2014 to 2016



Source: Solfanelli et at (2019) and Thommen et al. (2007)

Carrot supply chains vary depending on whether the end-product is consumed as fresh or processed: In both cases different stakeholders take decision on the variety choice (i.e. the farmer in the first case, the processor in the second).

A small number of well-established initiatives in organic breeding and seed multiplication of carrot could be identified in Germany, Switzerland, France and the Netherlands, using a variety of business models or financing strategies. A survey of some initiatives was carried in Germany out as part of a Master thesis (Herstatt, 2017) and by LIVESEED partners working on this crop in other WPs (e.g. INRA, University of Wageningen, Demeter International).

The seed supply chain of carrots in Germany will be studied through modelling in Task 4.2.2. There are around 800 organic carrot producers in Germany on an area of around 2100 ha with a resulting seed need of approximately 2520 Mio. Initial screening identified approximately ten seed companies in the Netherlands and Germany, mostly producing seed and cultivars for conventional and organic vegetable producers.

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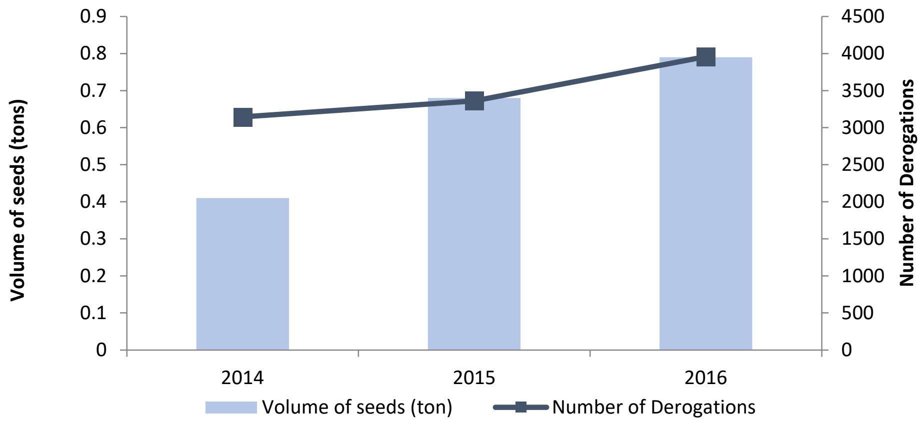
Cauliflower (Brassica oleracea var. botrytis)

Including a brassica crop as a focus crop was recommended by the external advisory group of LIVESEED. There is a need to carry out breeding activities for brassicas for organic farming, since cell fusion derived CMS hybrids are currently dominating the market (a cell fusion-free cultivar list has been issued by FiBL-CH).

There has been a considerable increase in non-organic seed derogations in Europe between 2014 and 2016 (by 382%) (Figure 7, data for 2004 are not available for this crop). Moreover, cauliflower is not included in Category 1 in any country and in eight countries (out of 12 with National lists) requiring no derogation. Additionally, the variety choice for cauliflower is usually taken by the transplant grower, which makes the cauliflower supply chain different from carrot supply chain. There also is past and ongoing work by the project partners ITAB and INRA in France, which is an important cauliflower producing country. Other project partners currently working on this crop within LIVESEED activities are Kultursaat e.V., Living Sementes, and Vitalis.

Figure 7: Volume of authorized seeds and the number of derogations for cauliflower from 2014 to 2016



Source: Solfanelli et at (2019)

Apple (Malus domestica)

Apple is grown in many European countries. Apple transplants are not included in Category 1 in any country that has national lists. It may be interesting from a market point of view to understand the implications of the actor making the cultivar choice, which can be made by the rootstock/scion producer and/or the farmer. In general, organic planting material of apples must be pre-ordered by farmers. FiBL-CH is in contact with some organic breeding initiatives which eased the collection of relevant information.

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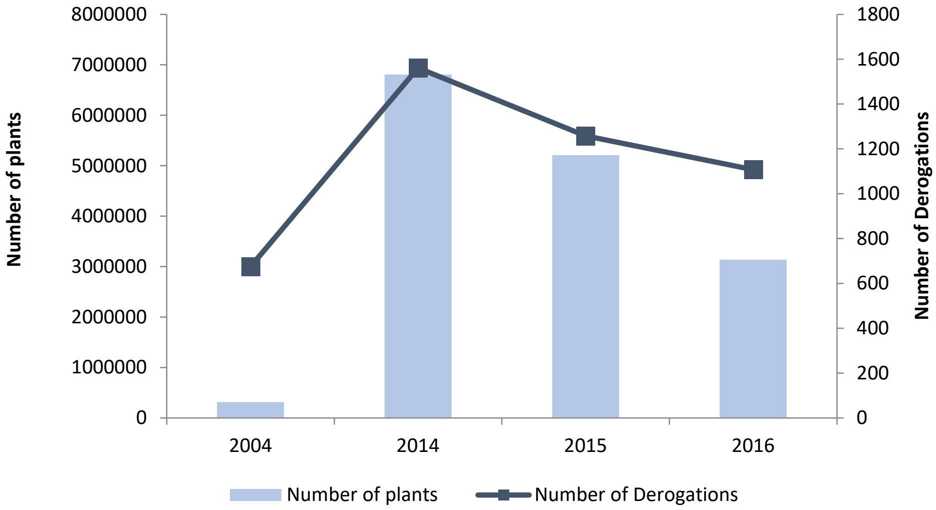
Figure 8: Volume of authorized seeds and the number of derogations for apples in 2004 and 2014-2016



Source: Solfanelli et at (2019) and Thommen et al. (2007)

3.3 Forage crops

3.3.1 General trends

Forage crops are very important in organic rotations and account for a large share of arable land. Clovers, grasses and herb crops will also be used in improving permanent pasture and may also be grown as catch crops between two main crops and as ground cover under permanent crops. Land use for (organic) forage crops includes both permanent pasture and temporary grassland in arable land. Permanent pasture represents the highest share of the organic agricultural land in Europe, corresponding to 5.7 million ha in 2017, i.e. 44% of the total organic land in the EU (Willer and Lernoud 2019). Counting temporary grassland in the arable land, we can conclude that organic forage crops represent the main crop sector for organic agriculture in the EU.

In the period between 2008 and 2017, the organic land dedicated to permanent pasture increased by 52%, with an increase by 4.6% in 2016-2017 (Willer and Lernoud 2019). A share of 8.9% of total permanent pasture in the EU is organic, which is higher than for arable land (4.6%) and lower than for vegetables (11.7%). By country, the largest permanent grassland is in Spain with more than one million ha, followed by Germany (0.8 million ha) and France (0.7 million ha).

The category of green fodder in Willer and Lernoud (2019) in the arable land area includes a number of crops important for the forage sector such as lucerne (alfalfa), clover, fescue, timothy and other grasses. These are also the crops for which more seed are needed. Organic land for green fodder accounted for almost 2.2 million ha in 2017, with an increase by 92% in 2008-2017. However, this figure includes also other crops than forage such as green maize and oats, but the crop breakdown within the green fodder sector is not provided.

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3.3.2 Organic seed use, derogations and regulatory issues

No specific literature relating to organic seed use in Europe for forage crops was found. The only study covering all crop sectors including forage is the survey conducted in the US by Hubbard and Zystro (2016). They reported a lower use of organic seed for forage in the US in 2014 than for the other sectors, with 59% average percent acreage planted to organic forage seed versus 69% and 78% of the vegetable and arable sectors respectively (Hubbard and Zystro 2016).

Farmers usually grow mixtures of several forage species and varieties, making it difficult to find organic seed for all the crop species and varieties needed in the mixture or needing to apply for many derogation requests. Countries have adopted different approaches for mixture, reducing the need require derogations for individual components (Table 8 below).

Table 8: Criteria for organic share in forage seed mixtures in different countries to be defined as organic seed

Criteria to avoid derogation request	Countries*
100% seed in the forage mixture has to be organic	• Austria, Denmark, Italy, Netherlands
At least 70% of organic seed is required	• Belgium, France, Germany, United Kingdom,
At least 60% of organic seed is required	• Switzerland
No explicit rule on seed forage mixture exist	• Greece, Hungary, Poland, Romania

*No information was made available for Portugal and Spain at the time of writing this report

Source: Information provided by certification bodies and national authorities implementing the national seed database

Austria, Denmark, Italy and the Netherlands require that all seed in the mixture has to be organic. Other countries allow a certain amount of untreated conventional seed by weight in the mix with no need to ask for derogation, if the minimum threshold is met. This is set at 70% in Belgium, France, Germany and the United Kingdom, and 60% in Switzerland. Some other countries in East Europe do not have an explicated rule in place for forage seed, which implies that farmers have to apply for derogations for every individual component in the mix. As a result, forage seed companies need to adjust the share of organic seed in the mix depending on the country where they sell seed.

Table 9 indicates the forage crops listed in Category 1 in different countries. As in the other crop sectors, the Netherlands is the country with the highest number of crops in Category 1 with seven forage species, followed by Germany, Luxemburg and Sweden with four species, and Switzerland with two species. Belgium and France have several vegetable and arable crops listed in Category 1, but no forage species. Table 10 shows the trends in derogations granted (volume of seed) in EU Member States and Switzerland from 2014 to 2016.

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Table 9: Forage crops in Category 1 (no derogations) in countries that have national Annexes in 2019

	Germany	Luxemburg	Netherlands	Sweden	Switzerland
Crimson clover				✔	
Egyptian clover	✔	✔	✔		
Persian clover			✔	✔	
Italian ryegrass			✔		
Perennial ryegrass			✔		
Westerwoldish ryegrass					✔
Sainfoin	✔	✔			
Tall fescue			✔	✔	
Vetch	✔	✔	✔		✔
Lucerne			✔		

Table 10: Evolution of derogations granted (volume of seed) in EU Member States and Switzerland from 2014 to 2016

Crop species	Increase in granted derogations (%) (percentage volume of seed)
Lucerne	+ 53%
Ryegrass (perennial and multiflorum)	+ 90%
Clover (red and white)	+ 72%
Fescue	+ 34%

*Public data on land area for these specific crops are not available. However, Eurostat data indicates that the land area for permanent grassland in Europe increased by 14% during 2014-2016, therefore only to a lower extent than the increase in derogations granted shown in Table 3 above.

3.3.3 Focus crops

We have selected two legume forage crops, lucerne which is commonly grown as a single stand, and white clover as the most important clover commonly grown in mixtures on organic farms. The third crop is a grass crop. All three forage focus crops are widely grown in the EU.

This diversity of the focus crops being studied ensures that different technical, supply chain and market issues can be considered. In the further description of the forage crop seed sector, we will also consider the use of forage crops mixtures.

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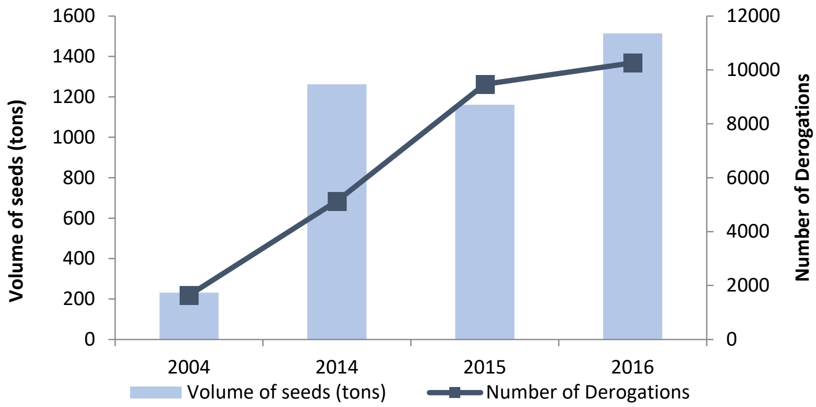
Lucerne (Medicago sativa)

Lucerne (also known as alfalfa) is a forage crop with the highest number of derogations in Europe (Table 9). Despite this, it is placed in Category 1 in the Netherlands. This diversity allows us to investigate the reasons behind these differences, e.g. whether it is related to technical and environmental issues or socio-economic and regulatory reasons.

The total volume of authorised non-organic seed and the number of derogations has increased since 2004 (Figure 9). Unlike many other forage crops, which are mainly grown in mixtures, lucerne is often grown alone. It is grown in most European countries, representing the major forage crop especially in Eastern and Southern European countries.

There is knowledge within the consortium about the crop, and breeding research activities are currently being undertaken by Agroscope and CREA.

Figure 9: Volume of authorized seeds and the number of derogations for lucerne in 2004 and 2014-2016



Source: Solfanelli et at (2019) and Thommen et al. (2007)

White clover (Trifolium repens)

White clover is widely used in forage mixtures in Europe. Data on derogations, aggregated with red clover (Figure 10), indicate a substantial increase from 2014 to 2016.

According to a Danish study, white clover is amongst the most challenging forage crops in terms of seed production (Boelt 2005). This makes it important to get an in-depth understanding of the breeding needs and traits, issues of organic white clover seed production as well as key bottleneck and solutions. Within the LIVESEED consortium, CREA in Italy, Agroscope in Switzerland and the German seed company Feldsaaten Freudenberger, which operates internationally, have in-depth knowledge of forage crops including white clover.

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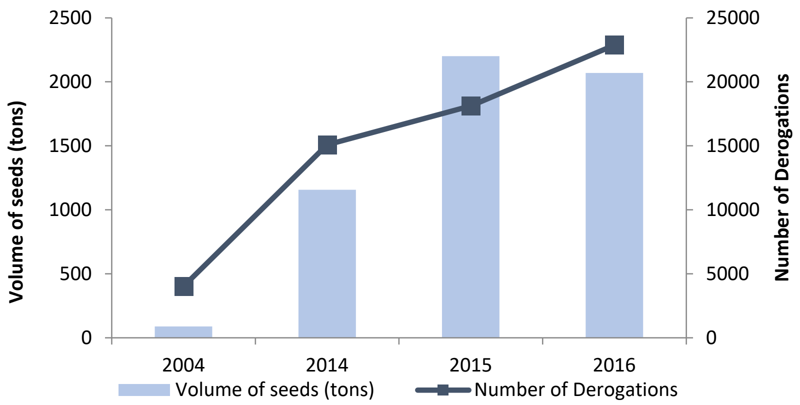
Figure 10: Volume of authorized seeds and the number of derogations for clovers (red and white) in 2004 and 2014-2016

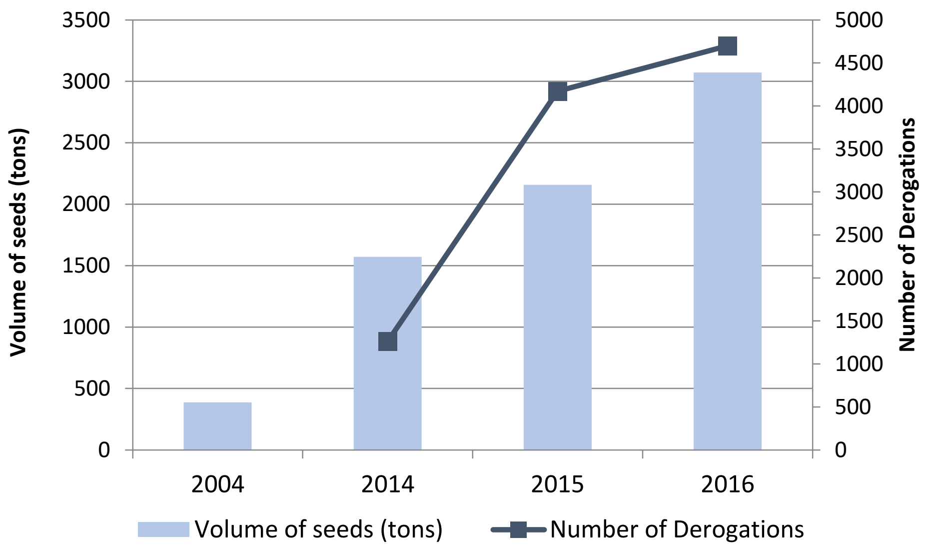


Source: Solfanelli et at (2019) and Thommen et al. (2007)

Perennial ryegrass (*Lolium perenne*)

Perennial ryegrass is widely used in forage mixtures across Europe. It is often mixed with clover species. Data on derogations are provided as pooled data with derogation data for multiflorum ryegrass. The aggregate data indicates the highest increase in derogations for the two crops from 2014 to 2016 within the European forage sector (Figure 11).

Figure 11: Volume of authorized seeds and the number of derogations for perennial ryegrass in 2004 and 2014-2016



Source: Solfanelli et at (2019) and Thommen et al. (2007)

There is knowledge within the consortium, for example by CREA in Italy, Agroscope in Switzerland and the German seed company Feldsaaten Freudenberger, which operates internationally.

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The seed supply chain of ryegrass in the UK will be considered in the modelling in Task 4.2.2., where ryegrass is usually grown as a mixture with clovers. Production of organic forage seed is very limited in the United Kingdom and most organic forage seeds are imported.

3.4 Differences in seed use and attitudes of organic farmers

Within LIVESEED a survey with 839 organic farmers in 17 European countries was conducted in 2018 to identify factors encouraging or discouraging farmers to use organic seed, and to explore other issues relating both to organic seed and breeding (for the full report see Orsini et al. 2019, LIVESEED Booklet #2).

The survey indicated many differences between the European geographical areas as well as some differences between the crop sectors. Farms were split into the categories of vegetable farms, fruit farms, arable farms and forage producing farms, according to the land area for and the market value of each crop.

The highest share of organic seed use per farm was found on farms that predominately grow vegetables, whereas the lowest share was found for forage farmers. Organic seed use in fruit farms was significantly lower than in arable and forage farms.

Farms in Northern and Central Europe had significantly higher use of organic seed than in Southern Europe, which in turn had significantly higher organic seed use than Eastern Europe.

Overall crops placed in Category 1 in at least one country (no derogation is possible) have amongst the highest share of organic seed use.

As for the forage sector, there is no significant difference between the countries adopting a 70% threshold for the mixture and those using the more stringent 100% rule.

The main critical issue reported by the surveyed farmers was the availability of organic seed for the varieties they need. This was true regardless of the crop sector, but it was significantly less pronounced in Central and Northern European countries. Also, the farmers claimed a lack of locally adapted varieties and a need for breeding for organic farming conditions, which they considered important to encourage organic seed use. This was true for the arable, vegetable and fruit sectors in all the study countries, but was less pronounced for the forage sector.

One survey question was about ranking some actions that are supposed to boost organic seed use. The farmers ranked as the two most important actions ‘Improve availability of organic seed for locally adapted varieties’ and ‘More effort to breeding programmes for organic farming’. For the latter, a statistically significant difference was found between vegetables and fruit farms on the one hand (higher ranks), and arable and forage on the other hand (lower ranks).

As for the action on the need to improve the availability of organic seed for locally adapted varieties, the ranking was significantly higher in Central and Northern than Southern and Eastern countries. The action ‘More information on availability of organic seed in foreign markets’ received a low rank, although significantly higher with farms in South and East Europe. Finally, the action ‘Stricter national rules for granting derogations’ was unanimously the least preferred action by farmers with no significant difference between crop sectors and countries.

The survey included a number of statements that farmers were asked to rank in a five-point Likert scale of agreement (from strongly agree to strongly disagree). Performing Kruskal Wallis test with Bonferroni adjustment, statistically significant differences were found between **crop sectors** for the following statements:

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- 'I want to use the newest varieties, whether organic seed is available or not', and 'I am encouraged to use organic seed by my certifier'– in both cases the ranks were significantly higher for vegetable and fruit than for arable farms
- 'The quality of organic seed that I use in my farm is high' – the rank was significantly higher for vegetable than fruit farms.

Statistically significant differences were found between **geographical areas** in the following cases:

- For the statements relating to the facilitating conditions, namely 'Organic seed is easily available for the varieties that I want to use', 'The quality of organic seed that I use is high' and 'Price for organic seed is accessible' the ranks were significantly higher in Central and Northern Europe than in Southern and Eastern Europe.
- For the statements: I'm positive about using organic seed', 'Organic seed is important to maintain the integrity of organic production', and 'Availability of organic seed has improved in the last 5 years' the ranks were significantly higher in Central European countries compared to other areas.
- 'By using organic seed I support the competitiveness of the organic sector' – the rank was significantly higher in Central Europe compared to Southern and Eastern Europe
- In Eastern countries the ranks for the two statements 'I am encouraged to use organic seed by my certifier' and 'My buyer expects me to use organic seed' were significantly lower than in countries in North and Central Europe and in South and Central Europe, respectively.
- 'I want to use the newest varieties, whether organic seed is available or not' – the rank was significantly higher in Central Europe compared to Northern Europe.

Finally, according to most respondents, the need for breeding for organic farming condition is 'very high' or 'high' for all the arable and vegetable crops considered. The situation is slightly different for forage crops, for which 'average' is the most frequent response, although still many farmers believe there is a need for breeding for organic. It is worth noting that in the case of forage crops, we have the highest rates of respondents, who selected the option 'I don't know' (up to 32% and 41% for Italian ryegrass and red fescue, respectively).

4 Results related to organic seed multiplication

4.1 Combinable arable crops (cereals and pulses)

4.1.1 General

In total, 29 interviews were carried, of which 20 were with companies, most of which were involved both in seed multiplication and in breeding activities of organic arable crops. The interviews were carried out in the following countries Denmark, France, Germany, Greece, Hungary, Italy, Poland, Romania, Spain and the UK.

The organic arable seed sector is characterized by small-medium companies that multiply organic seed and sell it to retailers or directly to farmers (Figure 12). They often establish a strong vertical integration upstream with breeders and downstream the supply chain with retailers. They may also establish alliances with other companies in the sector through outsourcing of the seed production process (i.e. farmers or farmer cooperatives). In some cases, the same company also carries out

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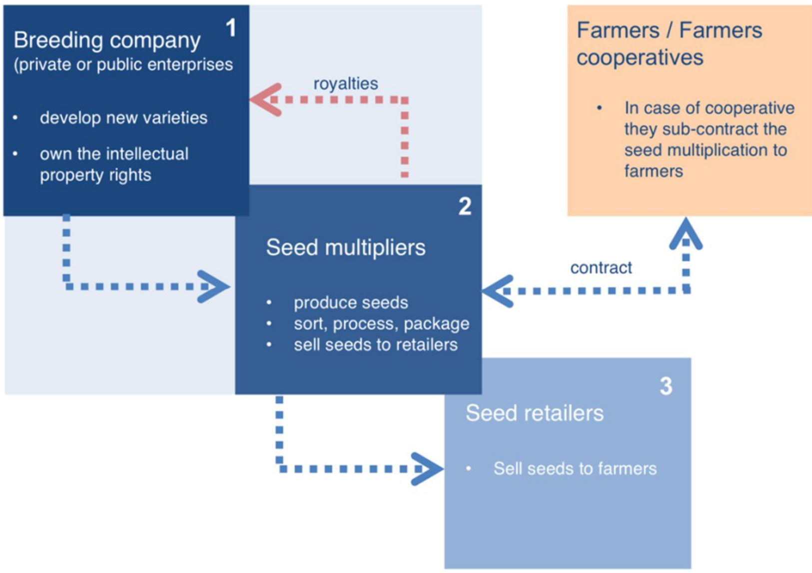
breeding, which is often observed for medium company and for soft and durum wheat (example can be found in Denmark, Germany and Italy).

Figure 12: The structure of the organic arable seed sector



Strategies and programs in organic arable seed multiplication also vary among crop and countries. According to the data collected in this study, two main approaches can be identified:

(i) Companies multiplying organic seed from both conventionally bred cultivars and/or organically bred cultivars. This first approach is mainly adopted by small seed companies or farmers' cooperative characterized by a high ethical involvement.

(ii) Companies multiplying both organically and conventionally (treated or not treated) seed from conventionally bred varieties. This second approach is mainly adopted by seed companies, which have entered later in the production of organic seed. However, they believe that the organic seed production is a growing market, which might become even more profitable in the next future.

Offering both organically and conventionally produced seed is perceived as increasing costs that are mainly related to scale and investment. Organic plots are often small and located in different areas, where organic farmers willing to produce the seed can be found. This is particularly relevant for small companies producing very small seed lots. The companies need to invest in separate seed cleaning facilities and storage to assure separation of processed organic seed in time and space from non-organic seed. This is difficult to justify if they consider organic market still relatively small and not stable over time.

In general, the interviews with arable seed companies reveal a growing demand for organic seed and a view of a strong positive development of organic seed multiplication sector across Europe. This is particularly true for countries, where the organic share of arable land is relatively high (i.e. France, Germany, Austria, and Denmark) and in the five countries that have official VCU or supplementary registration of organic wheat varieties (Table 5). In these countries, several varieties of wheat (mainly

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winter wheat) have been approved. Germany is the leading country, with 15 organic winter wheat varieties registered by F&Z Dottenfelderhof, Cultivari, Keyserlingk-Institute, followed by Switzerland with 10 organic varieties released by Getreidezüchtung Peter Kunz, France with five organic varieties, and Denmark with one organic winter wheat variety. In Switzerland, the plan to establish an official VCU trial for winter wheat under organic conditions had to be abandoned, because of costs and too little differentiation compared to the low input VCU trials. Instead one organic site is included in the official VCU testing locations for winter wheat. Bioverita[1], an organisation to promote communication of added value of organic breeding along the value chain, has listed by November 2019 a total 43 certified organic bred varieties and populations (19 winter wheat, 7 spring wheat, 10 spelt, 3 maize, 1 emmer, 1 triticale, 1 winter rye) from Swiss and German organic breeding initiatives. The situation is less positive in the rest of Europe. Countries in Eastern Europe are mostly dependent on imports of organic seed from other EU countries and on farm saved seeds.

The seed companies interviewed respond to the increase in organic seed demand across Central Europe (mainly in France, Germany, the Netherlands, Belgium and Austria) by adjusting their planned investments. Most of the respondents stated that they plan to increase their investments in organic seed production and supply in the coming year, although some also intend to remain close to constant or to decrease their investments.

However, the situation of organic seed production for cereals varies between countries. In addition to the certified seed market, farm-saved seed for own demand as well as informal seed systems play an important role in many EU Member States (especially in the South) in which farmers and cooperative produce and exchange seeds, mainly from local and traditional varieties and often only within their network. Compared to the total demand of organic seed in the EU, the quantities of seed exchanged in the informal seed systems are relatively small. However, the system has contributed to the development of new and alternative strategies for the production and distribution of organic seed. According to most of the companies interviewed, the objective of these initiatives are to help farmers to find solutions for the exchange of varieties that are not registered in the national variety catalogue and to create opportunities for organic processors and retailers in terms of product differentiation, communication and marketing activities.

4.1.2 Wheat (soft wheat and durum wheat)

The seed multipliers perceived the small range of organically allowed seed treatments for common bunt and other diseases as an important barrier to the development of organic wheat seed production in EU. Multipliers offering both organic and conventionally produced wheat seed consider the treatments allowed for organic seed (e.g. yellow mustard-powder, hot air and hot water) as not effective and too expensive. Moreover, the officially approved seed treatment varies among European country. Stakeholders in France and Austria also recognize the scarce availability of treatment for common bunt as an issue, but believe that the sector should invest more resources for the communication of existing techniques (e.g. workshop with organic farmers), rather than trying to find new solutions to the problem. An interesting approach proposed by ITAB in France (Rey at al., 2018) suggests managing the problem of common bunt from an eco-pathology perspective. The approach, first developed to study the health of herds in animal husbandry systems, focuses on the interaction

[1] List of organic bred varieties and populations with Bioverita certification 30 Nov. 2019 https://bioverita.ch/sortenliste-getreide-futterpflanzen/

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of multiple factors in the crop environment, rather than just on the interaction between a plant and its pathogen. According to Rey et al. (2018), several environmental factors and practices seem to influence the occurrence of common bunt. Seed companies interviewed in Switzerland indicate to focus more attention on soil properties and experience from Italy shows that common bunt disease poses fewer problems when the multiplication of the seed is done in the farms which implement a good rotational plan. Breeding for bunt resistance is probably the most promising strategy followed by organic breeders.

Weed contamination is another aspect seen as critically important by organic wheat seed producers as it affects seed quality. According to most of the multipliers interviewed, seed cleaning facilities (e.g. cleaning, grading, and brushing) can assure high-level purity and normally target specific weed seed contaminants, but a high level of contamination in the field can lead to rejection after inspection from the seed certification authority, depending on the implementation of regulations on seed health and contamination thresholds in each Member State. Outcompeting weeds is seen as an important strategy in organic wheat seed production. For this sowing density and the spatial arrangement of plants can play a crucial role, especially for a conventional bred cultivar with low tolerance to intensive harrowing. A seeder prototype was built in collaboration with a public research institute in Italy to optimize seed distribution in durum wheat. Seed multipliers in southern Italy perceived this innovation as an important step forward for the cultivation of durum wheat seed, as this can ensure a competitive ability against weeds (see De Vita et al., 2017).

According to interviews with multipliers, high yield losses due to the occurrence of weed and diseases may prevent farmers from entering into contract for seed multiplication. Many multipliers reported problems finding farmers who are willing to multiply organic seed under contract. Among companies interviewed, some suggested to establish a more collaborative approach between farmers and multipliers in order to help the chain members to deal with uncertainties and to achieve revenue enhancement. Naspetti et al. (2011) and Simatupang and Sridharan (2004) cited a variety of potential benefits of collaborative planning, including costs reduction and improvement of efficiency. A successful example of collaborative approaches along seed production supply chain was found in the North of France, where two organic farmers' cooperatives joined forces to establish a seed company.

Collaboration can improve the competitive advantage in several different ways:

- **Information sharing along the supply chain**: This can enable actors to efficiently plan and control their activities. Two cooperatives in France and Italy share appropriate information in a timely manner, which supports farmers and other stakeholders (e.g. updated information on national and communitarian regulation, technical requirements for seed certification and market development).
- **Decision synchronization**: This refers to joint decision making when planning logistical processes. The two cooperatives have a good system for synchronizing decisions, the technical staff plan in advance, together with the farmers all the logistics involved with seed multiplication, starting from delivery of basic seed for sowing till the collection of the harvest of certified seeds.
- **Incentive alignment:** This refers to the degree to which chain members share costs, risk and benefit. The two cooperatives implement appropriate incentive, such as compensation in case of crop failure, sharing the major cost of potential markdowns.

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- **Capacity building:** cooperatives can pool financial resources to build common infrastructure for seed drying, clean, testing, packaging, marketing and distribution of organic seed.

The implementation of the derogation systems differs among EU Member States (Solfanelli et al., 2019). Seed multipliers in Denmark and Italy considered the current derogation regime as an obstacle to their activities, rather than an effective instrument to regulate the organic seed market. One multiplier in Italy argued that derogations for the use of conventional seed are clearly necessary, if there is little availability of organic durum wheat seed. However, it was also pointed out that the derogation to use conventional durum wheat seed remains possible, even when the database appears to indicate availability of organic seed. The fact that farmers can easily avoid the use of organic wheat seed, simply by stating that none of the available cultivars in the database is appropriate, is seen as limiting the growth of the organic seed sector in Europe and create competitive disadvantage for the seed companies. This result was partially confirmed by the studies of Andersen et al., 2016 and Raaijmakers and Schaefer, 2019). According to two medium-large seed company in France and Italy, the availability of an adequate variety choice that satisfies the need of the farmers is the key to increase the use of organic seeds.

At the same time, seed companies should implement an effective vertical cooperation with downstream actors such as retailers and farmers. This would allow coordinating supply chain ordering policies for some established organic varieties, allowing seed companies to plan ahead and thus avoiding the problem of unsold organic seed. A win-win situation needs to be found, with seed supplier and retailers benefitting from increased income from seed sales and organic farmers from an adequate seed variety choice. Besides, the organic seed supply chain should find links with other actors of the organic value chains (i.e. millers, bakeries, retailers). A well-established product value chain could create demand for high quality organic seed. Examples are organic grains cooperatives in France, where the organic soft wheat market pulls the demand for organic soft wheat seed. A similar example is from Marche region in Italy, where pasta makers now source more than 70% of their organic durum wheat locally. The supply chain is supported by funding from the Rural Development Plan as an integrated supply chain project. The project is characterized by an overall framework agreement signed by the main stakeholders involved in the value chain, such as farmers' cooperatives, brokers, processors and retailers. The next step is to formally include also seed producers and breeders in the project.

Different implementation of seed regulations related to health and contamination in different EU Member States on seed trade also has to be considered. Norms for tolerant bunt spores on certified wheat seed differ between countries: in France and Spain there is a strict approach for the number of spores, while in Austria and Germany a higher threshold is applied (Micheloni et al., 2007). According to multipliers, this could create problems of competitive disadvantages. This might improve with the new EU Plant Health Regulation (2016/2031), which will enter into force on 14th December 2019.

According to multipliers in Romania, Hungary and Spain, the government should encourage the use of organic seed by linking it to receiving agricultural subsidies. Currently, this measure is implemented only in Estonia. The impact of these payments on organic seed market development is difficult to estimate. However, according to Raaijmakers and Schäfer (2019), this measure can only be effective, if there is enough suitable organic seed on the market. Also, the subsidies can help the sustainability and competitiveness of the sector only, if this is done strategically, supporting the quality of organic seed for a wide range of wheat varieties needed in organic.

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In many EU Member States, the variety trials are considered crucial by many seed companies to boost the organic seed market (see also Table 5 above). Variety trials provide farmers with important information about wheat cultivars adapted to their practices, the regional production conditions and markets. However, it is essential that beside on-stations trials, varieties are also tested on-farm in different climatic regions as this gives more accurate variety performance assessment (Kovács and Mariegaard Pedersen, 2019). Durum wheat variety trials have been set up only in Italy and Greece, while for soft wheat variety trials exist in many countries. Dissemination of results is also important. In many countries it is mostly organized by researchers coordinating the trials. However, competent authorities should develop an official list of recommended varieties for organic producers. For soft wheat, such recommended lists are already implemented in France, Italy, Switzerland and Germany.

Many initiatives can be found around EU, in which farmers produce and exchange conservation varieties and heterogeneous materials in a less formal way. Two interesting initiatives are presented below. The first initiative is an organic farm located in southern Italy selling traditional seed varieties both to his community and to farmers outside the network. The farm is a member of the Italian Seed Network, Rete Semi Rurali (RSR), from which it gets the technical support to solve issues related to the production of soft and durum wheat seeds coming from alternative breeding approaches. The farm has a long-lasting relationship with the Gene bank in its region. It receives local seed varieties from the gene bank and evaluates and multiplies the genetic material. The main aim of this activity is the *in-situ* conservation of the genetic resources for breeding. Thanks to the provisions of EU Directive on Conservation Varieties (2008/62/EC), the farm could become a certified seed producer with on-farm seed production license, and was the first in Italy to register varieties on the National variety list and produce certified seed of Sicilian wheat conservation varieties Maiorca, Timilia and Perciasacchi. The local farmers' seed network "Simenza" was created in 2016 to support the registration of more than 50 Sicilian local wheat varieties held by its members. This process led to the official field inspections and seed quality check at the packaging stage and the use of certified seed labels.

The second initiative is an organic farm located in northern Italy, mainly working with heterogeneous material and populations. The farm started this process in 2010 when a population of durum wheat was introduced on the farm, as part of the EU research project SOLIBAM. The performance of the population on the field was monitored by researchers and technicians. This process of evaluation through experiments led to the registration of the population with the Italian Ministry of Agriculture as part of the European experiment on the marketing of populations of wheat, barley, oats and maize (2014/150/EU). The farm started cultivating the population on a larger area of the farm and to produce seed. Seed production on the farm is now visited annually by the National Competent Authority to control the quality of the crop and, if the quality is good, allows the farm to sell the seed. The same process takes place now in different farms in Italy and the goal is to have a system of population seed production adapted to different environments that can be sold to the farmers interested in cultivating this type of heterogeneous material in similar environments. Since 2017 organic seed of this population is sold as certified seed directly by the farmer.

The modelling in task 4.2.2 will focus on the seed supply chains for organic durum wheat in Italy. The examples of vertical integration will be considered alongside the use of untreated conventional seed and farm saved seed.

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4.1.3 Lupine

In recent years, lupine has been considered an interesting protein crop as alternative to oversea soybean imports especially in cooler regions. Lupine is characterized by similar high percentage of protein and good amino acid composition. Nevertheless, its cultivation is still insufficient in both conventional and organic agricultural systems to ensure stable supply for both food and feed industry (Lucas et al., 2015). According to Abraham et al. (2019), the low number of breeding programmes is one of the factors that has hampered the development of the lupine crop in Europe. In the past years, the anthracnose disease in white lupine (*Lupinus albus*) has shifted the focus of the European lupine production sector almost exclusively onto blue lupines (*Lupinus angustifolius*). However, under good growing conditions and if not infected by disease, white lupine is characterized by a higher yield, higher protein content and higher competitiveness against weeds. Blue lupine has a shorter production cycle, which allows this crop to be grown with good performance also in the central northern European countries. Blue lupine is cultivated mainly in Germany, Poland and Switzerland, while white lupine is produced in France and in the Mediterranean countries (Italy and Greece).

Currently, organic lupine seeds available in the market are coming from conventionally bred varieties which are multiplied under organic conditions.

The multipliers interviewed in our case studies confirmed the importance of collaboration along the supply chain members to establish a sustainable competitive advantage for lupine producers and supply chains, including breeders and seed producers. Germany is the EU country where the organic lupine supply chain is relatively well established. Organic lupine has a 40% share of the total lupine area. According to the multipliers, the growing demand is linked to a strong developing market for high-quality animal feeds, which could be met by grain legumes such as lupine. Indeed, there are ongoing studies regarding the extension and improvement of soybean, pea, fava bean and lupine cultivations under the scope of the protein strategy of BMEL (Federal Ministry of Food and Agriculture) to reduce dependency of protein imports. For example, yellow and white lupines are studied to improve the cultivation value and yield reliability. For yellow lupine, a variety with good anthracnose resistance and earliness was identified (Ruge-Wehling & Jansen, 2014).

4.2 Vegetables and fruits

4.2.1 General

In total 24 interviews were carried, of which 16 were with companies. Most of them were involved both in seed multiplication and in breeding of organic horticulture crops. The interviews were conducted in Denmark, France, Netherlands, Germany, Switzerland, Hungary, Romania, Bulgaria, Italy, Greece, Spain, and Portugal.

In seed value chains for organic vegetable production, there is often a high level of vertical integration with the same company involved in multiplication and breeding (Figure 13). For some crops that are grown from transplant, such as cauliflower, the transplant producer may also be involved in choosing seed and variety (Raaijmakers and Schäfer, 2019). Further, seed packaging is often done by an individual actor. If grafting takes place, such as for apples or tomatoes, the breeding of rootstock and scion may be conducted by different entities (Koller, 2017, personal communication). Moreover, horizontal integration has progressed rapidly in the last decades in the form of mergers of vegetable seed companies (Elsen *et al.*, 2013).

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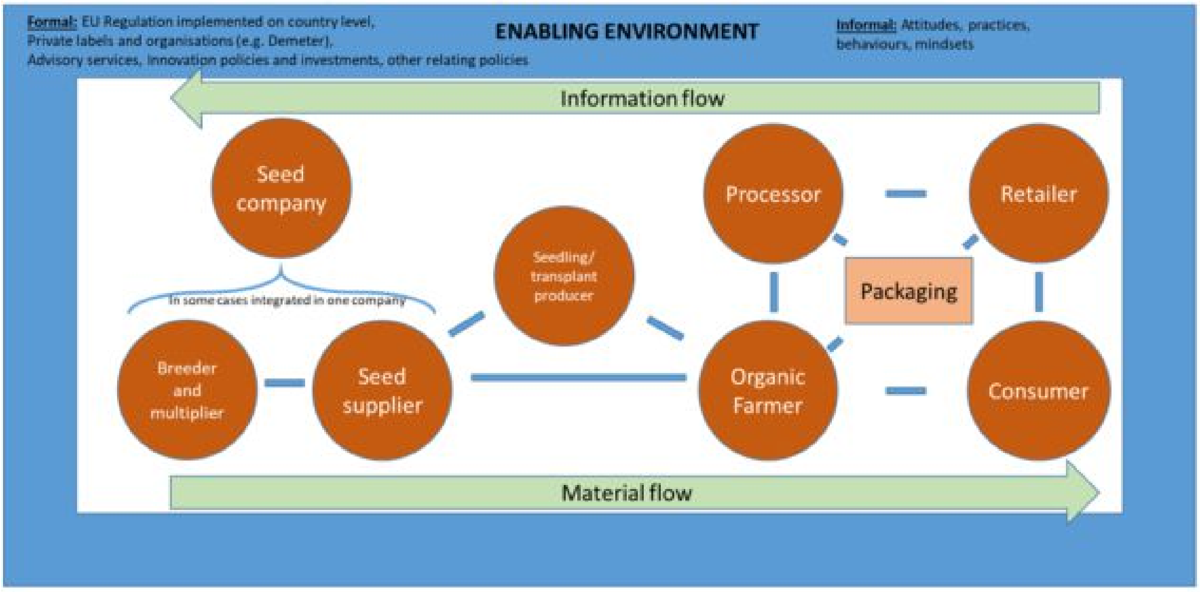
Figure 13: Organic fruit and vegetable seed value chain



For the focus vegetable crops of carrots and cauliflower, many medium sized or large companies in Europe produce seed from their own breeding activities (see also 6.2). Organic seed production for cauliflower and carrots mainly takes place in Western and Northern Europe and seed is exported to the rest of the EU. Also, Renaud *et al.* (2016) reported a lack of vegetable seed industry in many European countries, such as Portugal, Estonia and Bulgaria. For the perennial fruit focus crop of apple, plant reproductive material consists of rootstock and scion, often breed and multiplied by different actors. Especially the availability of apple rootstock suited for organic production is difficult to obtain.

Technical and regulatory challenges

A few common technical issues were identified with some differences between the types of companies and initiatives.

There is high pest and disease pressure in the production of organic vegetable seed, and a lack of effective methods for control in organic multiplication. This regularly leads to complete yield failure of the seed crop or low germination rates that render the seed lot impossible to sell. One disease example for organic cauliflower lacking in control methods is *Alternaria spp.* leading to yield losses (Köhl *et al.* 2010, Groot *et al.*, 2005).

Carrot and cauliflower are both biennial crops in seed production, which makes them more vulnerable to pests and diseases. The seed producing plant has to be overwintered and stays in the field for around 12 months, compared to annual seeding plants that only spend a few weeks in the field. Disease can also be passed on from the seed producing plant to the plant growing from that seed.

Furthermore, the interviewed seed companies reported that suitable climatic conditions for seed production are crucial and rare to find. Thus, seed production takes place all over the world under specific conditions. This is especially important for organic seed production, as it is more susceptible to the environment. Changing climatic conditions have already rendered some areas unsuitable, according to a Dutch seed company.

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Seed companies that sell organically multiplied seed from conventionally bred cultivars have specific problems with self-incompatibility in hybrids, as self-pollination cannot be entirely avoided. Further, it is challenging to keep parent lines in good enough health under organic conditions.

Companies and initiatives that focus on organic breeding and multiplication of open pollinated cultivars have the advantage that multiplication is generally less expensive than for F1 hybrids and not as technically complicated. However, since the marketable yield of open-pollinated cultivars of cauliflower is still substantially lower than F1 hybrids, the seed cannot be sold at the same price level.

Interview partners in all countries and from all types of companies and initiatives mentioned that the possibility for producers to apply for derogation severely hampers the development of organic vegetable seed and fruit planting material production in Europe. This is also mentioned frequently in the literature (e.g. Döring *et al.* 2012).

Differences in costs

The interviewees give as main reasons for differences between the organic and the conventional seed production technical difficulties at multiplication level, a higher risk of yield losses, the absence of certification, and traceability costs to the same extent as in conventional seed production. Vegetable seed crops need more labour, special seed handling equipment and apple more land and years for multiplication.

Companies that produce organic seed at a larger scale and are not local community-based initiatives generally list their offers in their home country as well as in other European countries. Small scale or exclusive initiatives cannot list, if the cultivars they multiply are not registered or choose not list their offer. In France, for instance, the interviewed farmer-breeder association reported that small scale breeders who cannot or do not want to go through the formal registration process of a new cultivar, cannot legally sell their seed. Switzerland has a law under which heirloom as well as novel cultivars can be registered as niche cultivars without official DUS and VCU testing. In total 51 different vegetable cultivars including 11 potato cultivars were registered by November 2019. Commercialized of seed of such niche cultivars is allowed (with area restrictions) within Switzerland (Richter, 2012).

Smaller farmer-centred initiatives finance their multiplication through volunteering, donations and memberships. Larger companies re-finance through seed sale. This is possible for them as they rarely have separate breeding programmes for organic seed production, but multiply conventionally bred cultivars under organic conditions.

Situation in specific countries

Mostly small to medium sized seed companies in the Netherlands, Germany, Switzerland and France see organic seed production as an investment in a growing market and as a promising business opportunity. They produce only a small amount of seed in their own country, but most seed is produced in more favourable climatic areas all over the world. The countries where the seed companies are located are also the same countries that have National Annex, listing crops for which derogations using non-organic seed (Category 1 lists) are no longer possible.

There is only limited organic vegetable production in Denmark, and there is no production of organic vegetable seed or fruit transplants at a larger and professional scale. Seeds are imported. Larger seed suppliers consider the market size to be too small to be of large interest for them.

In Spain, the production of organic seed for the vegetable sector has increased over the last years, but not at the same level as the area of organic vegetable production. The main challenges mentioned are the higher costs and technical difficulties as well as limited knowledge how to overcome these

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bottlenecks in organic seed production. There is also a lack of recognition of these higher costs from consumers and farmers, which makes an expansion of organic vegetable seed production difficult to finance. A small-scale vegetable farmer-breeder group in Spain specifically reported difficulties to access sufficient labour and organic land for their multiplication activities.

In Italy, farmers associations organise the seed production and breeding process for organic fruit and vegetable. Some small-scale initiatives that provide open-pollinated organic vegetable seed for crops like carrots, chard, sweet pepper and tomato face the same challenges as organic seed producers in other parts of Europe: Difficulties arise in ensuring plant health at multiplication level and in regulatory issues.

There is one smaller-scale organic breeding and seed initiative for vegetable in Portugal. The remaining seed is imported, although the organic seed use for vegetables has increased in the country, especially for top crops in sales like tomatoes, peppers, brassicas, cauliflower, carrots and aubergines.

Of the Eastern European countries, the organic seed offer and production have stagnated over the last years in Romania. According to the interviewed experts this stagnation is due to relatively low investments and lack of specific know-how to produce seed organically.

In Bulgaria, in recent years there has been no significant change in the organic seed production sector. There are few organic producers in Bulgaria who work with a limited number of crops. There is a total of 10 organic producers of seed and planting material: two for vegetables, one for hazelnuts, two for strawberries and raspberries, one for oilseeds, two for medicinal and aromatic plants, one for lavender and one for vines. This sector is not yet well developed in Bulgaria.

No activity on organic seed for the vegetable and fruit sector could be identified in Greece, which is attributed to a lack of know-how but also lack of demand. The national organic seed database is empty and very few distributors and retailers circulate imported organic vegetable seed in the market. It was mentioned that in order to promote organic seed production and use in Greece as well as in most other European countries, incentives for seed producers have to be created to develop national seed production. This requires analogous developments and support of organic production and the market in the country.

4.2.2 Carrot

Nine of the eleven interviewed vegetable seed companies or initiatives work with carrots and of those seven also work with organic carrot cultivars or organic seed. Many of the larger vegetable seed production companies and initiatives no longer attempted (organic) carrot seed multiplication, because it cannot be produced indoors, and outdoor production is still very challenging.

The organic breeding initiatives that produce open-pollinated cultivars are small and not or to a very limited extent internationally active. Estimates indicate that about 90% of the seed is from conventionally bred and conventionally multiplied cultivars, 9% of organically multiplied and only 1% of organically bred cultivars.

A leading Dutch vegetable seed company stressed that for carrot specifically, there is the need to improve pest and disease control in outdoor production areas that are bigger than 5 hectares, because from this size on, netting in the field becomes challenging. The lygus beetle is one of their major problems in the favourable carrot seed production areas.

Regarding hybrids, the costs to produce organic carrot F1 hybrid seeds are 100 to 200 % higher than conventional multiplication and variations between years are large. This is mostly due to the technical

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difficulties in seed production, hence the greatest cost differences between organic and conventional F1 Hybrid carrot seed occur during the multiplication process at farm level.

There used to be regulatory incentives in Denmark to encourage organic seed production and use through an agreement between the government and organic vegetable producers to use 40 % organic seed of carrot. However, this measure was not powerful enough to spark such a development, as there is still a lack of availability of suitable varieties of organic seed. The main seed company selling vegetable seed for the organic sector in Denmark is an importer of organic seed produced by Dutch companies. It is a challenge to produce organic carrot seeds with the necessary germination ability and germination vigour under organic field conditions. If germination is lower and seed are more expensive, the incentive for the organic farmer to buy organic seed of carrots is very low, so these technical issues result in a loss of farmers' trust and market share for organic seed producers.

In France, carrot is in Category 1 of the seed database since 2018. This decision has been taken after an alert a few years in advance that this will happen and discussions with seed suppliers as to overcome possible obstacles. The French expert group is concerned that some regions may encounter seed shortages, namely those where *Alternaria spp.* is a common issue. Genetic material of alternaria resistance is owned by conventional breeding companies and not yet available for organic seed producers. This is a hands-on example illustrates the difficulties faced by countries implementing Category 1 crops.

4.2.3 Cauliflower

Most of the companies and initiatives working with organic vegetable seed also produce organic cauliflower seed.

Cauliflower seed can be produced indoors which makes organic multiplication easier than for carrots. Members of seed initiative in Britany report difficulties for autumn cauliflowers, because the cycle of the plant is not coherent with the season (they are producing their curd in autumn, and then it is difficult to conserve the plant in order to have them flowering in spring). Other difficulties arise in organic seed production with respect to pest damage throughout the biennial growth cycle by insects (aphids), rabbits, and pigeons.

The French farmer-breeder initiative reported that most steps of their seed production and plant breeding of cauliflower are different from conventional producers and more decentralised. The farmers are breeding open pollinated populations instead of F1 hybrids, produce their seed in the fields (sometime under plastic tunnels), process their seed collectively (machines are owned by the association) and each farmer stores its own seeds (sometimes freezing part of the seed as a safeguard).

A leading Dutch seed companies reported that there is now a tendency of organic farmers in Central Europe to be willing to use F1 hybrid organic seed of cauliflower, since the seed price is not so much higher than the conventional F1 seed price (20 – 30%). The same is true for all vegetable hybrid seed production that can be carried out in greenhouses or poly tunnels.

However, in Germany the major organic label organisations (e.g., bioland, Naturland, Gaia, Demeter) have banned F1 hybrids of brassica vegetables which are derived from cell fusion, while F1 hybrids developed through the natural occurring self-incompatibility (SI-hybrids) are allowed. This ban is also imposed on imported organic vegetables. In Switzerland, Bio Suisse will ban such cultivars as soon as there is a sufficient choice of alternative cultivars available. The waiver of cell fusion derived F1 hybrids causes a severe bottleneck in the organic production and a barrier for seed companies to enter organic seed production, as this is the normal procedure in conventional breeding. Certain Dutch breeding companies maintain their SI hybrids specifically for organic seed production to cover this demand. In

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the scope of LIVESEED several open pollinated varieties developed by organic breeding initiatives are presently tested in comparison to SI hybrids in Central and Southern Europe.

4.2.4 Apple

The value chains for organic apple planting material are different from vegetables. Apple transplants are grafted, with rootstock and scion produced separately, and the interaction between the different producers plays a major role in producing organic propagation material. Cultivars are often bred and used within clubs with exclusive usage rights. Here, vertical integration can be observed at all levels of the seed value chain.

Organic material of both rootstock and scion is missing in most countries, due to technical difficulties. One major challenge under organic conditions it to keep both 100% virus free. There are now some Dutch organic rootstock producers, but growing scions organically is particularly challenging, due to sanitary requirements (lack of control methods for aphids as vectors of viruses). Also, apple trees are affected by soil fatigue, making the acquisition of new land necessary every few years. Using organic methods, it can be more difficult to achieve the same uniformity of the branches and height as in conventional production. This causes problems for the apple producers, as apple orchards are highly mechanised. As a result, only 60 - 80% of all organic trees can be marketed.

The main cost for apple multiplication is the special equipment needed for handling of the vegetative propagation material and also disease precaution during multiplication, special technical skills (e.g. for grafting) and more time than vegetables at the multiplication stage. The organic apple trees are 30 – 50 % more expensive than conventional apple trees, and the yield of the organic apple transplant is often lower.

It is difficult to produce the quality of transplants under organic conditions due to lack of knowledge. Furthermore, due to the lack of a secure market, it is risky to invest into an improvement of organic apple transplants. Following the value chain further up, since there are so many club cultivars, it is sometimes a challenge to obtain access to a promising cultivar that seems suitable for organic production.

With regard to regulatory aspects, in Germany, one of the smaller initiatives for organic apples in Germany has lobbied for and achieved that there are some regulatory barriers for organic pomaceous fruit producers to get derogations: Farmers have to pre-order organic apple transplants at least 12 months before hand. This gives the transplant producer some security and they are more willing to produce organic transplants. In contrast, for stone fruits, there is virtually no organic plant material available and there are no additional regulatory obstacles for getting derogation. Finding expertise can be a barrier for organic apple producer associations, as it can be very difficult to find tree nurseries that produce organic trees and also to convince the farmers to try out the organic transplants. It helps if there is already some trust established.

The availability of organic transplants has increased slightly in Germany and Switzerland. Apple trees are often locally produced in tree nurseries using rootstocks that are often imported from the USA, although there is now some organic rootstock production in the Netherlands.

Interviews with Spanish partners indicated that the production of organic plant reproductive material is not developed. The usual procedure is to use conventional propagation material which undergoes a conversion period. There are some small local breeders working with local varieties that do not use

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non authorised fertilisers, plant protection products or herbicides with the aim of increasing adaptability and resilience when planted in organic fields.

4.3 Forage crops

4.3.1 General trends

This section reports the key facts and issues relating to organic seed multiplication as emerged from the interviews and the existing literature. Overall 15 interviews were conducted on the forage sector with experts and seed companies, covering seven countries: Denmark, Germany, Italy, Lithuania, Romania, Switzerland and the United Kingdom.

In the interviews with project partners and seed companies it could be established that Denmark followed by Germany are the main producing countries of both organic and conventional forage seed. Production of organic seed for grass and clover takes place mostly in Central and Northern Europe, whereas organic seed for alfalfa is mainly multiplied in the Mediterranean countries.

All companies that were interviewed have slightly expanded their organic production of forage seed over the last 5 years (with the exception of the company in Romania), following an increase in demand. The Lithuanian seed company that we interviewed started producing organic and conventional seed for forage relatively recently in 2013. They saw a market opportunity as a consequence of the combined effect of the increase in organic land area in Europe and of the greening measures within the EU Common Agricultural Policies (CAP).

It is important to note that seed companies do not relate the positive trend in the market to the expansion of the various categories of grasslands in organic farming rather than a decrease in non-organic seed derogation per farm.

A fundamental problem of organic seed use in the forage sector is that farmers do need to grow forage in sufficiently diversified mixtures, and it is often difficult to find organic seed for all the crop species and varieties needed in the mixture. All the experts and the private seed companies reported a trade-off between selling (or purchasing) the organic mixture on the one hand, and selling (or purchasing) a mixture which is as much diversified as possible according to the needs of organic farming on the other hand. The benefits of using diversified forage mixture including herbal leys are widely confirmed by scientific literature (e.g., Annicchiarico et al. 2019; Brophy et al. 2017; Storkey et al. 2015; Hammond et al. 2014; Luescher et al. 2014; Li and Kemp 2005).

Most companies mainly sell already prepared mixtures with the share of organic seed depending on the minimum threshold set by the rule in place in the country where they are selling the seed. Other companies, which have closer contacts with farmers and also advise them on mixtures, are also preparing seed mixtures for specific conditions and on farmers' requests. This allows them to tailor the seed species and variety choice to the specific need of different farms, but it can be more demanding for the business in terms of operations management.

Another issue of selling already prepared mixture is connected with the registration of forage seed on the organic database (including organicXseeds): the database reports on the availability of individual crops rather than mixtures and does not give an indication if the crop is actually already in a mixture with other seed species and must be purchased as part of that mixture.

There seems to be consensus amongst the interviewees that there are some inbuilt difficulties in increasing the use of organic seed in the forage sector, which can be summarised as follows:

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- The market is considered to be relatively new and small[2] compared to the vegetable and cereal organic markets. This would explain the limited availability of organic forage seed for a wider range of varieties. Among the companies interviewed, the share of gross annual seed-related turnover from organic forage seed is still relatively small, ranging between 1% and 10%. The offer is particularly scarce for crops used in herbal leys such as sainfoin, chicory, birdsfoot and ribgrass[3], despite their increasingly recognised importance in organic farming. The same appears to be true also for the most commonly used crops including grasses and clover[4].
- Production of organic seed for forage is concentrated in a few Central European countries, which according to some interviewees (i.e. experts and companies in Eastern and Southern European countries and the United Kingdom) causes the available organic seed varieties not necessarily to be suitable to the farming environments of the importing countries.
- Only two out of the ten companies interviewed undertake variety testing (only under conventional conditions) in the countries where organic seed is exported.
- Variety testing for forage is conducted by seed companies in pure stand of individual varieties, which does not reflect the dynamics of the intraspecies and interspecies interactions when they are cultivated in mixtures. An exception is white clover, which is trialled in the UK with grasses as it suffers from low competitive ability relative to grass companions. This is an issue for both conventional and organic forages, but diversity in organic farming tends to be even higher than in conventional (Atkinson and Watson 2019).

All of the ten companies argued that using a whole-mixture approach with 70% as a minimum threshold of organic seed would be desirable as a harmonised approach at European level. In their view it would allow more room for manoeuvre in the preparation of the mixture so that the crop species and varieties would be more easily adjusted to meet the farmers' demands and would help reducing derogations.

A few examples were found in our case study research, where seed companies sold forage seed mixtures with 80% of organic seed to farmers in countries where 100% of organic seed is required, with the approval of the certification body and no need to apply for derogation. In these examples, the case was made by the seed company and the particular farm context required a more persistent variety of white clover in association with grass and that organic seed for that variety was not available. Such a case-by-case application of the rule allows tailoring the seed provision to specific needs, but it may also lead to a lack of transparency. Instead, a common rule on the organic share of seed mixtures would inherently be more flexible than the 100% organic forage seed requirement and might reduce the risk of such a case-by-case approach and deviation from the rule.

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[2] No publicly available market data exist. However, a Defra report published in 2003 estimated that grass and clover conventional and organic seed accounted for only 1% of the seed purchased by farmers in the UK (Defra 2003).

[3] For example a search for the availability of organic seed for forage herbs on the OrganicXseed database (21/11/2019) indicated that no organic seed for chicory or ribgrass was found

[4] For example, a search on OrganicXseed (21/11/2019) showed that organic seed for perennial ryegrass in the UK was available for five varieties. The recommended list for England and Wales 2018/2019 indicate a much bigger number of varieties corresponding to 70 recommended varieties for perennial ryegrass (British Grassland Society 2019).

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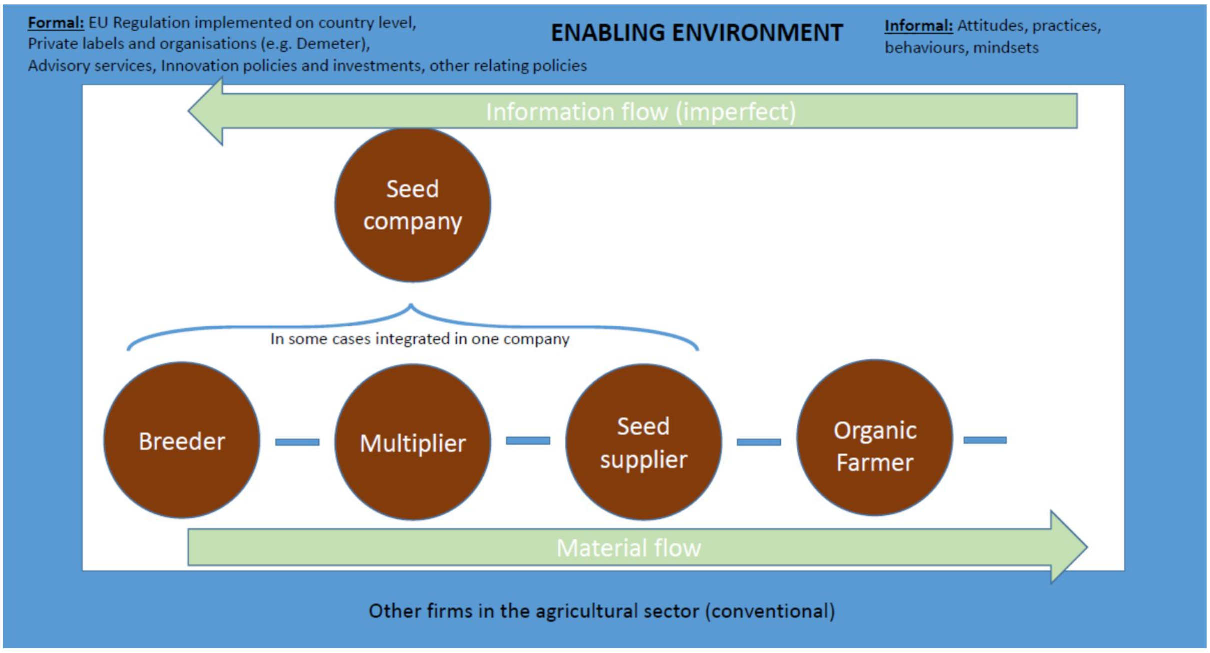
Regarding the seed multiplication process, the producers (normally contracted farmers) grow forage crop varieties in pure stand, with each farmer usually growing only one variety. This makes it easier for the inspection as well as the post-field operations in particular the seed drying and cleaning, which are a critical part of the production and purity of organic forage seed. In some cases seed producers get paid by the seed company for the amount of cleaned seed, in other cases the seed company pays for the raw material and then undertakes the cleaning itself or through external contractors. This mostly depends on the organisation of the business, rather than on the seed crop in question.

A typical example for the forage seed supply chain is represented in Figure 14*: Forage seed supply chain*

below. Breeding and seed multiplication in most cases are undertaken by different companies, but some examples of bigger companies concerned with both breeding and seed multiplication were found in Denmark, Germany and the United Kingdom.

In Figure 14 below we show that in the forage sector interaction in the supply chain takes place only between seed companies and farmers, in contrast to the other crop sectors, where examples of interaction and integration between the seed multiplication stage, and the market actors of the whole food chain (such as processors and retailers as well) were identified. This is likely to be related to the fact that forage crops are used by livestock and as such they do not go directly through the stages of processing and consumption by end-consumers.

Figure 14: Forage seed supply chain



In the next subsections seed multiplication aspects specifically relating to perennial ryegrass, white clover and lucerne are reported. A common problem for the three crops and the forage sector in general as emerged from the interviews and scientific literature (Boelt 2003; Gislum et al. 2003) is that forage species for seed production establish very slowly compared to cereal crops and for most species a satisfactory seed yield is not obtained until their second growing season. The slow establishment results in weak competitiveness against weeds. Therefore, organic seed production of

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grasses, clover and lucerne requires that weed control is carried out in the crop rotation in the years between seed crops. Seed yield is therefore also an important selection goal in forage breeding.

4.3.2 Perennial ryegrass

Seed multiplication for perennial ryegrass takes mostly place in Northern and Central European countries, where it represents the most commonly used forage grass in many pasture seed mixes. It is often sown in short-term leys (temporary grassland) together with clover and other forage species. Perennial ryegrass is listed in Category 1 only in the Netherlands (see Table 9).

The interviewees reported some technical/agronomic issues in the multiplication of perennial ryegrass under organic conditions compared to conventional. One of the most essential problems is the difficulty to provide adequate nutrient supply, especially nitrogen, which results in lower yields. Varieties are usually tested in VCU trials under conventional conditions, with a relatively high input of nitrogen. Ryegrass seed crops are also very sensitive to the timing of nitrogen application. Correct timing stimulates reproductive development, whereas excessive and poorly timed nitrogen application will favour vegetative growth (Boelt 2003). Overall seed companies reported lower yields for organic production compared to conventional, with reductions ranging from about 20% (according to most seed companies) to up to 40% (according to one of the two German companies interviewed). Scientific literature on this is limited to research carried out in Denmark many years ago, which reports a yield reduction in organic perennial ryegrass seed production of approximately 25% compared to conventional (Boelt 2003; Gislum et al. 2003).

The Danish, the Lithuanian and the Swiss companies interviewed reported that another major problem for organic seed production for perennial ryegrass and grass in general relates to the post-production stage. Whereas weeds are reported by these companies to be somehow manageable during production, they often represent an issue for the subsequent crop because of the chaff left on the field after the harvesting of grass, resulting in serious weeds problems which are difficult to fight. The three companies stated that this is often a reason for farmers deciding not to multiply grass seed organically.

4.3.3 White clover

As perennial ryegrass, seed production for white clover also takes mainly place in Central and Northern European countries. White clover is not listed in Category 1 in any country.

As other nitrogen fixing legumes white clover does not have the same issue of nitrogen supply in seed production, as is reported for perennial ryegrass. The difference in seed yield between organic and conventional systems is similar at harvest, but depending on weed contamination organic seed yield after cleaning can be even 50% lower than conventional. Yield reductions under organic conditions can also be caused by pests, such as weevil larvae.

Seed cleaning from weed is reported to be the main challenge by all the companies interviewed, due to the combined effect of higher weed contamination than in conventional and the small seed size of white clover seed. White clover seed is indeed smaller than other clover and grass seed: it is approximately 1mm in length, whereas seed of red clover and perennial ryegrass is 3mm and 5mm, respectively. The seed cleaning operation is expensive, which leads to seed production of white clover under organic conditions costing twice than in conventional, according to the companies interviewed.

Defoliation is reported to be particularly relevant to organic producers since it decreases the competition from some broadleaved weed species, but late defoliations decrease seed yield due to a removal of a large number of flower heads.

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While pure stands are used for seed production, the potential of forage crop cultivars depend on their performance in mixed stand with other species. Due to its relatively low competitive ability when grown together with grasses, seed companies in the United Kingdom test white clover in companion with grass. As emerged from the interviews, this approach of testing performance of a cultivar in mixture is used for white clover also in breeding and testing in Switzerland mainly under organic conditions. However, companies in most other countries normally test VCU of white clover cultivars in pure stand under conventional farming.

4.3.4 Lucerne (alfalfa)

Unlike perennial ryegrass and white clover, lucerne is usually grown in pure stands and harvested fresh, as hay or as dehydrated forage. Lucerne is in Category 1 only in the Netherlands.

Production of conventional and organic seed mainly occurs in Italy and France; conventional seed is produced also in countries of South and Eastern Europe (Romania, Greece), where most organic seed is nevertheless imported. Lucerne is used as a forage crop also in Central and North Europe, although the number of varieties suitable to cold and wet conditions is more limited.

The seed company that we interviewed in Romania is the only one in the country that is producing organic seed for lucerne also for the domestic market. The seed producer started producing organic seed in 2008 and has since then doubled his production. Demand has increased within the network of organic farmers that he can reach by selling organic seed for other crops as well (cereals and oilseeds).

As a legume, lucerne does not have problems with nitrogen supply in seed production. Two seed companies in Italy and Romania reported that seed production encounters similar issues to white clover: the seed is very small (about 3 mm in length) which causes severe difficulties in cleaning from weeds and requires good equipment.

Based on the interviews with the companies and the experts, lucerne is tested in VCU trials only under conventional conditions. Being produced mainly in pure stand, there is no need to for mixed stand testing. However, as part of LIVESEED the potential of breeding for mixed stand performance of lucerne with different grass species is tested in cooler regions in Switzerland, as this has not been explored in the past.

As for white clover, the yield between organic and conventional systems is similar at harvest, but depending on weed contamination organic seed yield after cleaning can be up to 50% lower than conventional.

5 Results related to organic plant breeding

LIVESEED refers in this project to the **definition of organic plant breeding** provided in the International IFOAM Norms on Organic Production and Processing (Version 2014)[5]:

(Article 4.8) Breeding of organic varieties

Organic cultivars are obtained by an organic plant breeding program which fulfil following requirements:

[5] https://www.ifoam.bio/sites/default/files/ifoam_norms_july_2014_t.pdf

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4.8.1 To produce organic varieties, plant breeders shall select their varieties under organic conditions that comply with the requirements of this standard. All multiplication practices except meristem culture shall be under certified organic management.

4.8.2 Organic plant breeders shall develop organic varieties only on the basis of genetic material that has not been contaminated by products of genetic engineering.

4.8.3 Organic plant breeders shall disclose the applied breeding techniques. Organic plant breeders shall make the information about the methods, which were used to develop an organic variety, available for the public latest from the beginning of marketing of the seeds.

4.8.4 The genome is respected as an impartible entity. Technical interventions into the genome of plants are not allowed (e.g. ionizing radiation; transfer of isolated DNA, RNA, or proteins).

4.8.5 The cell is respected as an impartible entity. Technical interventions into an isolated cell on an artificial medium are not allowed (e.g. genetic engineering techniques; destruction of cell walls and disintegration of cell nuclei through cytoplast fusion).

Most important characteristics of organic breeding programs is that **all breeding steps from crossing to final selections take place under organic conditions** and that the applied breeding techniques are in accordance with the techniques listed in the Annex of the position paper on Compatibility of Breeding Techniques in Organic Systems of IFOAM Organics International from November 2017[6].

Besides value and process oriented organic plant breeding, **product-oriented breeding for organic** was defined by Wolfe et al. (2008). This differentiation was further developed in the position paper on organic plant breeding by the European Consortium for Organic Plant Breeding (ECO-PB) in 2012[7]. Breeding programs for organic have a special focus on the breeding goals which are specific for organic agriculture (e.g. tolerance against seed borne diseases, weed tolerance, nutrient use efficiency), they do not apply critical breeding techniques, and selection occurred at least partially under organic conditions.

In the new organic regulation (EU) 2018/848 "organic varieties suitable for organic agriculture" have been defined for the first time in a legally binding context in Annex II 1.8.4. "For the production of organic varieties suitable for organic production, the organic breeding activities shall be conducted under organic conditions and shall focus on enhancement of genetic diversity, reliance on natural reproductive ability, as well as agronomic performance, disease resistance and adaptation to diverse local soil and climate conditions. All multiplication practices except meristem culture shall be carried out under certified organic management."

5.1 Combinable arable crops (cereals and pulses)

5.1.1 General

Strategies and programs in organic arable breeding vary substantially between crops and countries. According to the breeders interviewed and their activities, three main breeding approaches for organic can be distinguished:

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[6] https://www.ifoam.bio/sites/default/files/position_paper_v01_web_0.pdf

[7] https://www.eco-pb.org/fileadmin/eco-pb/documents/discussion_paper/ecopb_PostitionPaperOrganicPlantBreeding.pdf

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1. **Shared breeding program for organic and conventional with the same breeding goals**. Selection and propagation take place under conventional management from the initial stage until the late generations. The varieties developed are broadly oriented to the needs of organic and low-input farming, but perform well also in conventional farming systems. The breeders belonging to this category argued that conventional breeding goals are getting every year more similar to the organic; therefore, it is easier for them to develop organic varieties starting with the conventional approach. This model is mainly adopted by durum wheat breeding company, as well as by lupine breeders.
2. **Shared early stage breeding program for organic and conventional program and switch to certified organic condition in later generations**. The main difference to the previous approach is that the breeding program has a special focus on organic farming. For example, the initial stages (inter-varietal crosses and line selection) are common with conventional, whereas in the late generations specific traits are tested only under organic conditions. This approach is adopted both by small breeding companies and private or public research institutes. They often work in close collaboration with supply chain actors to develop innovative organic varieties that may better suit the needs of the organic sector. This approach is mainly used in soft wheat breeding programs.
3. **Breeding programme under certified organic conditions from the beginning to the end**. Organic breeding programs focus completely on the requirements of organic farming. This approach is mainly adopted by non-profit organic plant breeding associations, individual farmers, or farmer cooperatives engaged in participatory breeding. They are mainly financed by foundations (private donors), national/ EU project researches and partnership with members of the supply chain (producer associations, processors). This model is implemented for all of the three crops considered in this case study research.

While the first two approaches are considered as breeding for organic, the latter one is considered as organic breeding. Breeding companies may adopt different strategies for different crops. For example, a conventional breeder of durum wheat that was interviewed argued that he recently developed a breeding program where the late generations were selected under certified organic agriculture.

Main actors and stages

In terms of seed supply chain organization, mainly two different approaches can be found:

1. Breeders who conduct exclusively breeding activity (i.e. the bred varieties are usually sold to seed companies for multiplication), and
2. Breeders who manage all steps of the seed supply chain, from breeding to seed production and distribution.

The majority of the breeding companies focus their activities on the needs of conventional farmers and the selection is carried out exclusively under conventional conditions (i.e. no special breeding program for organic) or in the best case the breeding program for organics is shared with conventional. Nevertheless, as some of these varieties may perform relatively well under organic conditions, the breeding companies are usually investing in post-release organic varieties testing (and eventually in official VCU trials if possible) as to understand which varieties may be selected for the multiplication under organic conditions. This approach is adopted by the Italian wheat breeders operating in central and southern Italy, who developed and registered some new conventional wheat varieties which are currently being considered for the organic market (e.g. a cultivar named “Nadir” for durum wheat and a cultivar named ‘Ilaria’ for winter wheat). The same approached is used by the lupine breeding sector in Germany.

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Technical, regulatory and market challenges

In general, the breeders interviewed indicate a growing demand for organic bred varieties and a positive development of the organic breeding sector across Europe. Over the last five years, the average company's turnover of organic wheat breeding has increased by about 10% per year. The growth is higher in countries where there are official registration procedures for organic varieties and where organic arable farming is a well-established sector (i.e. France, Germany, and Denmark). The commitment of the supply chain actors to support organic plant breeding, as well as the involvement of farmers and farmer's associations in the breeding process have contributed to the investments in organic plant breeding.

5.1.2 Soft wheat and durum wheat

Breeding goals

The interviews show that several variety traits that are considered as priority by the organic breeders are not addressed in the same way by conventional breeders. These results are consistent with those found in the literature (see among others Osman et al., 2008; Wolfe et al. 2008), which show the need to implement concerted initiatives to develop wheat with traits specifically aimed at the organic soft wheat supply chain. For organic soft wheat, priority traits for organic breeders are baking quality, weed competitiveness and tolerance to harrowing. The need to include tolerance to harrowing in the breeding programs and, when possible, in the organic VCU protocols, was mentioned in Germany and Netherlands and specifically for winter wheat. According to Osman et al. (2016), tolerance to intensive harrowing is one of the breeding goals to be considered in the variety profile of the Dutch organic spring wheat. Resistance against seed-borne diseases (e.g. common bunt) and nitrogen utilization efficiency are also mentioned as a breeding priority for both spring and winter wheat and for both breeding for organic and organic breeding. In Austria, for instance, resistance against common bunt is the most important trait assessed in the organic VCU trials: the variety which shows resistance to common bunt is registered in the catalogue independently of the results of other traits. Table 12 shows the soft wheat traits considered in the organic VCU protocols implemented in some EU countries (see for more details Kovács and Mariegaard Pedersen, 2019).

The breeding goals in organic durum wheat differ between organic and conventional, as the later mainly focuses on the development of cultivar with high yield, high protein content and good resistance against fusarium. Small differences can be founded between breeders who adopt a breeding program for organic in common with the conventional and those who adopt a dedicated organic breeding program. While, nitrogen utilization, quick establishment and high resistance to fusarium head blight are present in both breeding programs, the later also focus on high tillering capacity and weed competition.

The need for specific breeding programs for organic durum wheat is intensively discussed among the durum wheat breeders (see among others Dinelli et al., 2013 and). According to de Vita et al. (2007) selection procedures have worked intensively to obtain durum wheat genotypes that performed well under high input agriculture systems, but their adaptability to organic agriculture was never considered so far. Crossbreeding of old durum wheat genotypes with new breeding lines are of special interest for the organic sector, as some traits typical of the old varieties such as adaptability and rusticity may be maintained in the new cultivar (Dinelli et al., 2013). Furthermore, the breeding programs for durum wheat did not give much consideration to the nutraceutical and nutritional characteristics of the final product. Recently, there is an increasing interest by the organic industry to

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develop cultivars with lower γ-gliadin and α-gliadin, which are two sub-fraction of gluten responsible for the immune-stimulating effect and for the toxicity to celiac patients (De Santis et al., 2017; Dinelli et al., 2013).

Organic VCU testing of soft wheat

Winter wheat is the most advanced crop with respect to established release and post-release organic variety testing. Table 11 lists the EU Member States that have implemented specific VCU protocols for the release of soft wheat for organic farming. These VCU trials are conducted under organic farming and adjusted traits have been developed which are of relevance to the organic sector.

Despite the interest among breeders and seed companies, official organic VCU protocol has not yet been developed for durum wheat in any EU Member State. However, post-release organic varieties trials of durum wheat are currently performed in Greece and Italy (see for more details Kovács and Mariegaard Pedersen, 2019).

Table 11: Traits considered in organic VCU trials of soft wheat for those countries that have implemented specific VCU protocols for the release of soft wheat for organic farming

Country	Traits considered in the VCU
Austria	weed competitiveness, resistance against common bunt, nitrogen efficiency, quality parameters (weight, protein content, gluten content, sedimentation, falling number, starch content), baking quality
Denmark	yield quality parameters
France	yield, protein content, baking parameters, weed competition
Germany	weed competitiveness, resistance against disease, milling and baking characteristics, gluten content
Latvia	winter hardiness, lodging resistance, plant height, resistance against diseases, vegetation period days, quality parameters (weight, protein content, gluten content, sedimentation, falling number, starch content)

Main actors and stages

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Information sharing along the wheat value chain is considered essential by many breeders, particularly by those who develop a breeding program under certified organic conditions from the beginning or in early generations. On the contrary, breeders adopting no special breeding program for organic, which are usually those implementing a high centralized approach, are usually less motivated to establish stable collaboration with members of the supply chain. This result is consistent with those found in Ceccarelli and Grando (2007) and Morris and Bellon (2004), according to which collaborative approach (e.g. participatory plant breeding approaches) is expected to be particularly advantageous where seeds end-users (farmers, processors or even retailers) require uncommon traits and where the improvement of crops are mainly oriented to develop local products.

To select the best cultivars, breeders have close collaborations with the supply chain actors. Public institutes and small companies working with soft and durum wheat have also stable and good relationships with both millers and bakers/pasta makers, from which they can get support in the selection of the right traits to be included in the breeding programs. According to Verrier et al. (2019), collaboration within the food chain is of crucial importance to develop long term successful initiatives. A high number of the cases examined in the soft and durum wheat supply chain benefits from the experience of the organic farmers to support specific decisions. However, some breeders argued that it is difficult to have stable collaboration with farmers for the following reasons:

(i) farmers have a limited time and resources to dedicate to the breeding initiatives;
(ii) lack of proper strategies to manage Participatory Plant Breeding (PPB) initiatives;
(iii) PPB initiatives are usually financed by short term research projects.

According to Medum (2010) several socioeconomic obstacles must be overcome to establish effective PPB methods, but the lack of funding to develop and organize the technical skills needed in the network is the major obstacle.

Organic breeders argue that carrying out all steps of breeding, from crossing to selection and maintenance, under organic conditions is important aspect as it hallows to breed wheat cultivars that are fully suited for organic growing conditions. This has also been acknowledged in the new EU Organic regulation stating that the development and marketing of varieties suitable for organic agriculture should be promoted.

Technical, regulatory and market challenges

Common bunt (*Tilletia caries* and *Tilletia foetidia*) and loose smut (*Ustilago nuda*) are the main plant disease in wheat. In conventional farming and breeding disease is controlled by seed treatment with synthetic fungicides. According to the breeders interviewed, a few measures can be used to control common bunt disease in organic breeding. These vary from the use of natural admitted treatments to the removal of spores by specific brushing machines /air screen cleaning. The organic breeders in Switzerland and Germany stated that until last year, seed treatment was done with Tillecur, which is a powder based on yellow mustard seed. This product is no longer allowed in Switzerland and therefore breeders were obliged to use alternative products (e.g. bio-agents in combination with milk powder), which are, however, not specific for the treatment of common bunt. Fortunately, mustard seed is now regulated in the EU and Switzerland as basic substance and therefore can be applied by farmers, without notification.

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Weed is pressure is another major challenge in organic wheat breeding. Hand weeding is an expensive practice, particularly in the nurseries, where the wheat crop presents even little competition with weed. Weed harrowing is an established technique used by breeders, but is not sufficient in certain years. In these cases, hand weeding is the only feasible solution.

Organic breeders stated that, besides weed and pest control, there are several other technical difficulties which may affect the efficiency of the organic breeding process. Organic breeding differs from conventional breeding in many aspects, particularly regarding the type of techniques and tools used from the initial inter-varietal crosses until the selection in late generations:

- Difficulties encountered at the beginning of the selection program (production of genetic variation through crosses of different wheat parental lines). According to the breeders, synchronization of the flowers is always an issue in open field conditions, as stigma is receptive for a short period and pollen may not be available yet in that period. In these cases, organic breeders may only rely on staggered sowing date to achieve proper synchronization of the flowering of male and female wheat parents during crossing time, while conventional breeders can rely on several other tools (growth chambers; glasshouses; use of chemicals). However, small-scale breeding associations prefer to avoid these tools as they consider the interaction between soil and plant as the essential condition for the development of locally adapted organic crops.
- Difficulties encountered during the selection of breeding lines (selection of the best performing individual plants). According to one representative of a biodynamic breeder association, markers technologies can speed up the selection process and thus reduce the costs of breeding in general. However, they are not used by their association, as they argue that genomic selection completely neglects the genotype-environment interactions. In contrast, other organic cereal breeders join forces with universities to detect molecular markers for combining different bunt resistance genes in wheat in the scope of LIVESEED and ECOBREED projects. There is an intense debate in Europe on the applicability of molecular markers in organic breeding, particularly concerning the violation of plant integrity (Collard et al., 2005). Furthermore, according to Lammerts van Bueren et al. (2007), some of the most important traits considered in the organic wheat breeding (i.e. yield stability, disease resistance, nitrogen efficiency and weed competitiveness) are regulated by different chromosomes and thus complex and difficult to select for. Despite this, these techniques have been adopted by many small and medium breeding companies to select traits in the early wheat plant's development quickly and easily. Small breeders switching to certified organic status only in the final stages of the breeding program argue that their next strategies will consider higher investments in marker technology and genomic selection as they hollow them to save a lot of money for during the selection phases. Currently they can only outsource these practices to universities and research institutes, which lead to a general increase in their total variable costs.

Organic breeders in Europe have developed a wide range of composite cross populations, dynamic populations and farmers selections with higher levels of genetic diversity. However, they are not in compliance with the required DUS (distinctness, uniformity, stability) tests for variety release. In 2014 a temporary experiment for certain derogations for the marketing of heterogeneous populations of wheat, barley, oats and maize (2014/150/EU) was introduced and is extended till February 2021. Cultivars specifically develop for high level of within genetic and phenotypic diversity are defined as organic heterogeneous material and promoted in the new organic regulation (EU) 2018/848. From 2021 on, organic heterogeneous material in organic agriculture will be allowed with prior notification but without DUS and VCU testing. This shall promote the development of locally adapted populations with high resilience towards different biotic and abiotic stresses.

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Financial consideration and business models

Many breeders stated that the low return on investment of dedicated organic breeding programs is perceived as the main barrier, preventing breeding company from developing new organic wheat cultivars. According to the breeders it generally takes about ten years to develop new durum or soft wheat variety, from the initial inter-varietal crosses to the registration into the national catalogue.

The total costs for the development of new soft wheat varieties, including the costs for the registration into the national or European seed catalogue, can be estimated as follows, based on data provided by some of the interviewed breeders:

- 500,000 € (i.e. 50,000 € per year over 10 years) for breeders who adopt a dedicated organic breeding program under certified organic conditions from the beginning to the end (these data refer to winter wheat, as no data were available for durum wheat).
- 200,000 € for breeders who adopt a breeding program for organic shared with conventional

No data were provided for breeding programs in common where breeders switch to certified organic condition only late in the generations.

However, these cost estimates refer only to a limited part of the total organic and conventional wheat breeding initiatives that exist in EU countries and in Switzerland. Kotschi and Wirz (2015) estimated an average breeding costs of 350,000 € for organic cereals breeders in Germany and Switzerland per year. Furthermore, it is necessary to consider that the total cost for breeding one variety strongly depends on the company organization and structure. Nevertheless, this data is consistent with those reported by Osman et al. (2007), which show that the cost of a completely separate organic wheat breeding is more than double compared to the combined strategy where breeders switch to certified organic condition late in the generations.

Breeding activities in the main durum and soft wheat market are usually financed through a very small royalties or levy on the seed price of protected varieties (e.g. on average about 20 to 50 € per tonne). This condition is considered unrealistic by the seed companies interviewed, as organic varieties are grown only on a small area so far. In addition, the organic sector aims to increase the agricultural diversity growing a wide range of crops and different cultivars per crops. This would further reduce the royalties per cultivar. The option of increasing the levy on the final seed price is therefore, not realistic as it would result in a drop in the relative competitiveness of organic farmers. As a consequence, breeding companies prefer to spend most of their effort in selecting conventional durum wheat varieties, whose potential market is considerably larger.

Royalties are the main funding sources for conventional wheat breeders. As for many other crops in the EU, these royalties are included in the price that the farmer has to pay for the certified organic seed. According to the interviewed experts, these can vary a lot, depending on cultivar and countries. On average it goes from a minimum of 20 to a maximum of 50 € per ton of certified wheat seed. These data are consistent with those found in the literature (Osman et al., 2007). Organic breeders have to

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rely on other sources besides royalties for financing their breeding initiatives. These include sales of seeds (this is the case when breeding, seed production and retailing are carried out by the same company) and research projects. EU funded research project was the main funding source in DK: one of the breeders interviewed claimed that breeding has so far been financed 100% from research projects from mainly public funds.

Donations are the main funding sources for non-profit organic plant breeding association. Private foundations cover on average more than 60% (varies from 35 to 81%) of the breeding costs of organic cereal breeders in Germany and Switzerland, while remaining income depends on royalties, public funding through participation in research projects and organic processors/traders (Kotschi and Wirz, 2015). Organic breeders also mentioned an increase over the last few years in the financial support from downstream stakeholders in the supply chain. These resources support in particular specific breeding projects and the development of a network of relationships among research institutes, breeders, processors, and promotion initiatives with organic consumers.

The question whether the level of collaborative planning and close supply chain relationships could help improve the organic wheat breeding sector was further explored to collect potentially successful examples. Alternative crop breeding models were developed in Italy and France to overcome some problems related to the limited scale and profitability. In Italy, a durum wheat collaboration project includes two biodynamic breeders from Italy and Switzerland, one large organic farmer's cooperative, one organic pasta maker and the biggest Italian organic specialized retailer. For the first time in the durum wheat breeding sector, the breeding program has involved not only commercial and public breeding institute but also other important players within the pasta supply chain, such as farmers, processors and traders of the final product (Figure 15). The project was entirely financed by private funds and is based on the strong commitments of all members of the "consortium", who had worked together to develop a new cultivar specifically adapted for Central Italy organic system. In 2018 the "consortium" has started the registration of a new candidate variety named "Inizio" (which in Italian means "beginning") in the official national Catalogue. The variety will be tested in the conventional VCU testing, as there are no official VCU trials for organic varieties in Italy. This has caused concerns amongst the supply chain actors, as the variety could fail conventional VCU. This example emerges as a very well-established network, among which an intense debate is ongoing on how to speed up the process of implementing an organic VCU protocol for durum wheat in the country.

The lack of organic VCU trials is seen as an issue in many other EU Member States. For example, other breeders in Switzerland, Netherlands and Spain confirm that the variety registration is currently an obstacle for the development of new varieties, as no specific variety release protocol for organic cultivars exists. This means that the organic varieties are tested under the same conditions as conventional varieties, with a relatively low chance to pass the VCU test. According to Pedersen (2012) it is important that the VCU trials, which are mandatory in the EU for the registration of arable crop varieties, can also be conducted under organic conditions, to encourage breeders to select varieties for organic farming.

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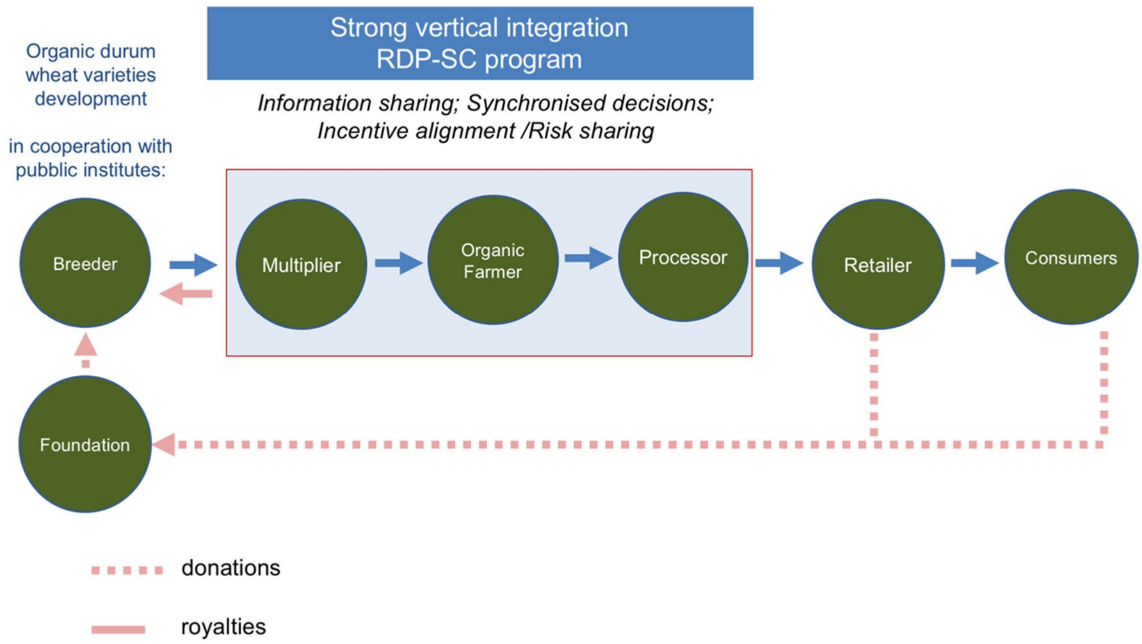
Figure 15: Organisation chart of the durum wheat value chain including breeding and seed production



Collaborative approaches were also adopted by many other initiatives in Switzerland, Italy, France and the Netherlands. There is an increasing interest among both consumers and industries (bakeries and pasta makers) in the identification of specialty products made with particular varieties (i.e. varieties with lower γ-gliadin and α-gliadin content) which are considered healthier, especially in the organic and functional food sector. In Italy, for example, the collaboration between upstream actors and retailers (specialized organic) resulted in specific agreements to support the breeding initiative of a local association working with ancient grains composite cross populations (CCP) of both soft and durum wheat. At the beginning, the project was financed only by public funds and donations, but is now gradually moving to a model where the total cost is financed by the retailer and consumers. The final product, which currently represents a small part of the total turnover sales, is a high quality (niche) product that achieves a relatively high price (i.e. about 50% more than the average price of organic pasta in Italy). The idea is to finance all costs for breeding activities with a small amount of the total final price at retail level (now is about 2%). The challenge is to increase this percentage, as there is a growing awareness of retailer and consumers on how to share responsibility and cost for food production. In Switzerland, another example of value chain collaboration that includes one organic breeder, farmers, millers, a baker and a big supermarket retailer was identified. The integrated supply chain produces bread that is sold under the brand "Bioverita" indicating that the bread is derived from organic bred cultivars.

5.1.3 Lupine

Decision 2014/150/EU providing for certain derogations for the marketing of populations of plant species. To the best of our knowledge, there are no organic lupine varieties specifically developed for the needs of the organic systems. Organic farmers can rely on a relatively small number of conventional varieties, which in some countries are multiplied under organic conditions. In Germany,

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for instance, there are four different varieties of blue lupine registered in the organic seed database (e.g. “Mirabor”, “Boregine”, “Salsa”, “Zeus” and “Boruta”), while in the French database there is only one variety of white lupine (i.e. “Amiga”). Other EU countries such as Italy and Spain rely on non-organic untreated seed coming from France and Germany and on local ecotype. Therefore, joint breeding activities are conducted in CH, IT, NL and FR to develop organic cultivars of white lupine in as part of the LIVESEED project.

Breeding goals

Most of the breeders involved in this survey claimed that there are not substantial differences in breeding goals between conventional and organic. Nevertheless, some traits may be more important than others when breeding lupine for organic farming.

Anthracnose is the most important disease in white lupine production, and represents a barrier in production. The identification of cultivar more tolerant to this disease is one of the main goals of organic breeding. Germany and Switzerland are the EU countries where most of the breeding initiatives on disease resistance of lupine come from, particularly for what concerns white lupine. A German seed supplier is the maintainer and does the marketing for the new conventional white lupine (*Lupinus albus*) variety called "Frieda". This variety was bred supported by public funding by Institut für Pflanzenbau und Pflanzenzüchtung of the Bayerische Landesanstalt für Landwirtschaft in Bavaria, Germany. A second new conventional white lupine variety named “Celina” will be probably registered in Germany in the next spring. Both varieties (“Frieda” and “Celina”) are claimed to be more resistant against anthracnose than the known cultivars and could be easily adopted by the organic seed multipliers. In Switzerland, the project “LupinBreed” aims to identify anthracnose-tolerant cultivars adapted to the organic condition since the first generations. This project is managed by FiBL in close collaboration with the organic farm BioBöhler and the organic breeder Getreidezüchtung Peter Kunz (GZPK). The idea of the project is to identify the most promising white lupine lines tolerant to anthracnose to start the selection and breeding.

Drought tolerance and adaptation to calcareous soils is another important trait which is currently considered for the selection of organic white lupine in the Mediterranean areas (Italy and Spain) and the Netherlands. Some white Lupine landraces have been identified in Italy, thanks to the work of CREA, for both drought tolerance and adaptation to calcareous soils.

Weed competition is another important trait currently considered by the breeders. Tall plants are to be preferred in organic farming as they show a higher weed competition. Increase of oil content in lupine seed, which now is about 8-15%, would probably increase the economic sustainability of the crop in general. The crop could become a dual-purpose crop like soybean (protein and oil) and therefore the industry would invest more money for the development of the supply chain.

Technical, regulatory and market challenges

A joint effort to expand and improve the breeding and processing of lupines for animal and human nutrition is seen as critical to developing the potential of this crop by many multipliers in Germany and Switzerland. Different initiatives have started to establish networks integrating all supply chain actors. For example, in a lupine network project in Germany (which is part of the Federal Protein Strategy), a key point is the exchange of information between researchers, consultants and farmers.

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Lupine is also one of the crops involved in the European Protein2Food project (2015-2020) which is aimed at improving varieties, production and processing of protein crops for human consumption (e.g. lupines, faba beans) and seed crops containing specific high-quality proteins (e.g. quinoa, amaranth). In Switzerland, the project "LupinBreed" aims to identify anthracnose-tolerant cultivars adapted to the organic condition since the first generations and to develop the most promising white lupine lines tolerant to anthracnose through selection and breeding. This should help to re-introduce white Lupin in Swiss agriculture to develop local value chains for human consumption and animal feed.

According to the breeders, one of the main bottlenecks in lupine breeding programs is the narrow genetic base, which limits the adaptive potential of the crop to the organic conditions. According to the Swiss and Italian lupine breeders, lupine breeding has exploited little of the gene pool, as crosses are mainly conducted within the sweet lupin genepool (mutants with strongly reduced alkaloid production). This is partially due to the need to maintain the alkaloid content as lower as possible. To overcome this problem, breeders in Europe are trying to make crosses with germplasm coming from foreign countries (such as Chile and Australia), landraces from gene banks and/or using local ecotypes, mainly coming from the southern EU countries.

Another problem lay to the fact that lupine plants are mainly self – pollinating, while certain degree of cross-pollination (about 10 to 15%) can occur via insects. According to the breeders, the prevention of outcrossing through the use of a specific net is the main technical barriers, which generate higher variable and fixed costs.

5.2 Vegetables and fruits

5.2.1 General

Main actors and stages in different European countries

In the Netherlands, Germany, Switzerland, and France, there is a strong contrast between two trends:

- **On the one hand**, the monopolisation and privatisation of vegetable breeding (a trend that can be observed world-wide), where only profitable crops are of interest. For example, a leading vegetable breeding company has recently given up conventional carrot breeding entirely due to low return of investment, although it can by no means be considered a niche crop. Interviews with these actors show that they also see no apparent need for separate breeding programmes for organic agriculture.
- **On the other hand**, smaller companies and initiatives especially in the organic sector, take up a wider range of crops and develop new cultivars. Mostly, these initiatives work with open-pollinated cultivars, in order to maintain a greater genetic diversity for improved resilience and to restore farmers' abilities to produce vegetable seed for specific cultivars.

In the Netherlands, there is a larger organic breeding and seed company that produces organic hybrids for pumpkin, zucchini, rootstock tomato and sweet pepper, but not for carrots or cauliflower. Smaller organic breeding initiatives develop also organic carrot and cauliflower cultivars.

In Germany there several small non-profit organic breeding initiatives spread across the country that work on organic vegetable breeding including also carrots and cauliflower.

In Switzerland, one commercial organic seed and breeding company devoted to organic vegetable breeding is involved in organic carrot breeding.

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In France, there is a strong movement of farm-saved seed and participatory and on-farm breeding which has driven an increase in the production in vegetable seed. These farmers are convinced that organic seed and breeding are important for the organic sector and their own business. An example for this is a farmer's seed association and participatory breeding network in Brittany. Farmers produce their own organic seed and exchange open pollinated cultivars (OP) among themselves. Participatory research begun in 2000 with INRA Rennes. The objective was to breed and produce seed in coherence with IFOAM principles, in particular without cell fusion techniques and F1 hybrids. Farmers were searching for solutions to exchange and sell each other's varieties that are not registered. The association was created to manage this collective action.

In Portugal, one small-scale organic breeding initiative is preparing an organic carrot breeding programme in Portugal and Spain. Otherwise, there seem to be no organic breeding activities in Portugal.

In Spain, although there has been a slight increase of public and private investment in breeding programmes for the organic vegetable and fruit sector. Different regional agricultural research institutes have conducted research for the last years on the genetic improvement of local apple varieties. There is also a small farmer-breeder initiative that breeds, maintains, and sells organic and heirloom vegetable cultivars, among them cauliflower and carrot. Different regional agricultural research institutes have been working for the last years investigating on genetic improvement of local vegetable varieties including carrot and cauliflower to reduce pesticides and fertilizers' dependence, fix resistance to pests, select those that are more adapted to the regional soil and environmental conditions and that have better acceptance by farmers and consumers.

In Bulgarian research institutes, breeding activity is poorly developed due to the low investment. Breeding programmes for vegetables are developing for potatoes and cabbage.

In Greece, typical breeding goals for vegetable and fruit are pest and disease resistance, quality, shelf life, yield. Drivers for this change are climate change and the organic market development. Researchers and farmers are mainly responsible for the choice of variety. Suiting to farming conditions and adaptability are the most important for a cultivar, so that the demands of a growing organic market can be met.

In Hungary, Breeding for vegetable has been drastically cut down in recent years; historically it used to be financed by the government.

There seems to be very little organic breeding activity for carrot and cauliflower in Northern Europe, i.e. the Scandinavian countries, where breeding for vegetables and fruits is in general limited. In Denmark, mostly the same varieties are used conventional and organic agriculture. One conventional breeding company has some breeding activities aimed at the organic market, but under conventional conditions. One smaller German biodynamic breeding company has a large range of seed in the Danish seed database, but the professional producers do not consider these varieties homogeneous enough and do not use this offer.

For apple, there are much less organic breeding initiative in Europe and no organic bred cultivar has been released until now due to the long time (>20 years) needed for fruit crop breeding. Organic apple breeding is running in Switzerland, Germany, Denmark, the Netherland, France, and Greece. LIVESEED has established an apple breeding network to join forces among the different actors.

Main breeding goals and differences between conventional and organic

In general, yield, taste, size, shape, colour and uniformity are breeding goals that apply to most vegetables and fruits. Some goals are common with conventional, such as reducing days on the field,

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yield and taste, others such as tolerance against specific pest and diseases are more relevant to the organic systems, like soil- and seed-borne diseases as no synthetic seed treatment is applied or tree growth and architecture of apple trees as no synthetic thinning is conducted, and therefore, mechanical thinning need to be minimized. Organic breeders argue that there is also a strong need for separate breeding programmes in organic agriculture as in conventional breeding techniques are or will be applied which do not comply with organic principles and therefore, should be more regulated. Moreover, they highlight that there is a higher emphasis on breeding goals like taste, healthy ingredients, diversity, general resilience instead of specific resistances, and ecosystem services. A study by Cheatham *et al.* (2009) suggested that breeding goals should take more aspects into account. The authors emphasise the importance of going beyond increasing yield in the short them, and of including the concept of ecosystem services for breeding into breeding goals. Taking the more complex effects of diverse eco-systems and their services and dis-services to pest management into account and to incorporate the knowledge gained could substantially bring agriculture forward. A systems-based breeding concept has been developed as part of LIVESEED (Lammerts van Bueren et al. 2018).

Seed companies that produce conventional as well as organic seed argue that ultimately both conventional and organic agriculture have the same goals, i.e. to become more independent from external inputs. Miedaner (2018) raises doubts about the effectiveness of organic breeding, as the breeding process is less efficient without the use of modern breeding techniques. Furthermore, it is argued that most organic producers rely on conventional cultivars and seem to be coping well.

Technical, regulatory and market challenges

Organic breeders in Bulgaria, Spain, Switzerland, Portugal, Germany, Greece, and France developed a wide range of open-pollinated cultivars and farmers selections with higher levels of genetic diversity. Working with open pollinated cultivars, it is very challenging to pass the official DUS testing needed for variety release and marketing access. Moreover, these cultivars so far cannot always fulfil the standards set by conventionally produced F1 hybrids and therefore struggle to obtain market share. It is argued that this is due to a research gap of a few decades, as necessary knowledge and methods available for hybrid breeding still need to be developed for breeding with populations. This is the case for carrots, cauliflower, and other vegetables.

Furthermore, there are issues with cultivars specifically developed for high level of within genetic and phenotypic diversity, defined as organic heterogeneous material in the new organic regulation (EU) 2018/848. Until now it was legally prohibited to market such seeds, except for the cereals listed in the temporary experiment on heterogeneous populations. From 2021 on, organic heterogeneous material in organic agriculture will be allowed also for vegetables.

Financial considerations

Insecure funding, especially for long-term (about 10 years), is a main obstacle to get involved in organic breeding. The need for organic plant breeding has been ignored for many years and received attention only recently by farmers associations, several stakeholders and the scientific community (e.g. Lammerts van Bueren, 2009), which was confirmed by the LIVESEED farmers' survey. However, the available literature is still scarce and the existence of organic breeding initiatives is still unknown in many countries. This makes communication to value chain actors and lobbying in a political context difficult. The long period needed to breed a new cultivar and the probability to succeed in breeding a promising new cultivar makes this even more challenging.

Cost differences at the different stages of breeding (breeding, cultivar registration, maintenance breeding) are most pronounced at the breeding and selection stage followed by cultivar registration.

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Maintenance breeding is only a small part of the costs. Registration costs are the same for every cultivar, but if breeding is carried out under organic certification, organic certification costs are a substantial addition. Further drivers of cost differences are breeding schemes, such as participatory or non-participatory schemes, and how many breeding goals are targeted.

In both organic and conventional breeding, labour is the most important overhead cost, followed by infrastructure. Vegetable breeding requires more labour, whereas apple requires also land and skills. Compared to conventional breeding, organic requires more labour and scanning of the genepool for adaptability. Conventional breeding has costs for higher chemical treatment and the technology used is more costly. However, the results of population breeding in vegetables are by far not as market compatible as hybrid breeding results.

For the organic vegetable sector, funding for breeding is obtained in several ways, as illustrated by examples from different countries.

In France, the Netherlands, Germany, and Switzerland there are private vegetable breeding and seed production companies that fund breeding work through seed sales and royalties. Breeding is mostly carried out under conventional conditions and the cultivars produced are multiplied for conventional agriculture as well as for organic agriculture. Examples of cooperation between seed companies (SMEs) on bigger pre-breeding projects were also reported, if e.g. finding a certain resistance gene combination is complicated and costly. Participating breeders then have access to the genetic material and can go on developing their own cultivars based on that. The breeding sector is fast moving and actors have to be quick to be successful and also need capital to use new technologies and a large amount of data (e.g. DNA analyses). Around 30% of sales revenue is invested in research and development of new cultivars. There is a large discrepancy between the size of investments for re-financed mixed breeding programmes (conventional and organic) and pre-financed exclusive organic breeding programmes. Whereas around one to two million Euros are invested by private companies in the first case, substantially less is invested in the second case, because the breeding is mostly financed by donations. This also partly explains difficulties for organic cultivars to gain significance in the market.

In Denmark, there are no breeding activities for most fruits and vegetables (conventional and organic) and there are no other funding possibilities. Some organic variety trials were started as part of a research programme, and after the end of this programme trials have been continued based on project-based funding.

In France and Italy, farmers associations often organise the breeding process for organic vegetable agriculture. Furthermore, seed companies that re-finance their breeding activities are prevalent.

A government-funded organic breeding programme is considered the most promising approach for Italy, as the production size is not big enough to make breeding programmes for all relevant crops economically viable. So far, there are some small donation-based or cooperative-based organic breeding activities for local adaptation.

In Portugal, there is some funding by ethical and sustainable foundations and the EU for organic vegetable breeding projects.

In Spain, the most prevalent models for financing breeding are re-financing, cross-financing and non-profit organisations supporting the breeding process at farm level with a network of farmer-breeders. There is also some public-private co-funding.

In Romania, there is very little investment, if so through European projects like LIVESEED or some other public funding.

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In Bulgaria, there is some little public investment in breeding work at Bulgarian Universities. The most promising business models are pre-financing of breeding by the public sector and pre-financing of breeding by a public-private partnership. This is because re-financing is challenging and initial investment in organic breeding is higher than for conventional breeding, as there is still a large research gap.

In Greece, the governmental gene bank supplies some material to breeders (mainly working in state research institutes or universities), but no commercial seed companies have shown interest. Secondly, community seed banks and seed savers work on participatory evaluation and organic breeding, e.g. an NGO cooperating with state research institutes and Universities. A pre- financing of breeding by a public – private cooperation could be possible or refinancing breeding through commercial seed sales if seed market has been developed sufficiently. The most promising, at least for pioneer organic breeding and organic seed production in Greece, could be initiatives for organic seed production directly linked with organic growers or community seed banks with breeders, small scale seed producers and food chain (e.g. breeding and seed production projects organized by organic producers unions, social enterprises, NGOs, local authorities). Organic breeding then could be community supported and seed production at local or at least national level relying on national genetic resources minimizing imports of less adaptable or expensive seed.

5.2.2 Carrot

The organic breeding initiatives that produce open-pollinated cultivars are very small, and most organic carrot growers used conventionally bred and multiplied cultivars.

Breeding goals are largely the same for organic and conventional breeding and include yield, taste, size, shape, colour and uniformity. In terms of pests and diseases, for carrots the carrot fly, lygus beetles, *Alternaria* and *Xanthomonas* are of importance, and reducing pest and disease pressure is considered more urgent goal in breeding for organic carrot production. Furthermore, general resilience and yield stability under low-input conditions are also more pressing issues.

Some open-pollinated carrot cultivars have been developed e.g. by a bio-dynamic breeding initiative in Germany, where funding was obtained through the collaboration with a German processor. The breeding goal, i.e. specific requirements for taste, was pre-defined. One study by Geier (2013) points out that organically bred open-pollinated cultivars scored higher than conventional F1 hybrids as regards the indicator sweet taste.

5.2.3 Cauliflower

Breeding goals

The main driver for separate breeding programmes for organic brassica crops is to obtain cultivars that are cell fusion free brassica cultivars. Cell fusion derived CMS hybrids are dominating the market of brassica vegetables. In order to develop such hybrids, male sterility has been introduced by fusion of cauliflower cells with the cytoplasm of radish. Although allowed in the EU Organic Regulation, certain groups of organic farmers, breeders and consumers reject this breeding technique that does not respect the cell as an entity that should not be divided and is therefore considered by some label organisations as incompatible with organic agriculture. SWISSCOFEL (2019) describes the situation in Germany, Austria, and Switzerland, where a positive list of cell fusion-free cultivars is mandatory for organic farms with Demeter, Naturland, Bioland, Gaia and Bio Austria certification. For Bio Suisse farms, the list is mandatory with some exceptions such as cauliflower.

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Head size, taste, foil coverage and different colours are of interest in cauliflower breeding. According to a Dutch organic seed company, transplant growers are prevalent in cauliflower production, but they do not predominantly decide which cultivars will be used. For them, a good stability and uprightness of the plant is most important. This is considered in breeding.

For the French small-scale initiative, local adaption, quality (mainly taste, aesthetics), and diversification (creation of new types), to provide vegetable to the consumers during the whole year are important vegetable breeding goals.

Technical, regulatory and market challenges

The small-scale French vegetable breeding association highlights that labour and time for the breeding activities are the biggest obstacles to advance in organic breeding, as the farmers have their farms to run at the same time. For their selection, many plants and hence a large land area is needed. In cauliflower for example only 70 to 100 plants are kept out of 10 000 plants. Furthermore, the association wants to rely more on short value chains and funding of breeding activities through their actors, and not on the actors in longer chains. This has not yet been achieved.

Financial considerations

The initiative Fair-Breeding® is an example of innovative financing, where food trade actors can contribute a percentage of their revenue of organic product sales to a fund that goes into organic breeding. With this fund, three new open-pollinated cauliflower cultivars could be bred since 2008 (International, 2015).

5.2.4 Apple

Main actors and stages

Apple breeding used to be carried out by publicly funded organisations in Switzerland and Germany. Nowadays, mostly large tree nurseries undertake apple breeding in Germany, the Netherlands, Belgium, and France. There are some small organic apple breeding initiatives in Germany and Switzerland. These are locally active initiatives that are financed through membership of individuals or farms. Some members (organic apple producers) breed specifically for organic apple growers, although the breeding process is not certified. In addition, some necessary inputs are not organically certified, like the substrate for seedlings and the breeding process itself. The group opted against producing a club variety and will make the resulting cultivars publicly available through-licensing. In Switzerland one breeding initiative has been conducted exclusively under organic conditions since 25 years and is testing the best candidates in a European organic apple network as part of LIVESEED.

Our research did not identify any company in Greece, engaged with organic apple breeding, but some research and educational institutes have limited apple breeding activities with a focus of on organic breeding goals.

In Spain, some publicly funded apple breeding and organic tree production could be identified. A public research and agrarian services centre works with fruit varieties in Asturias, the North of Spain. The institute is specialised in breeding varieties of apples and of cider apples that are traditionally produced in the region, and sells vegetative propagation material directly to farmers or farmers' cooperatives. Until now, breeding has not been carried out under organic conditions, but there are plans to do this in the near future.

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There were some promising activities in Hungary in multi-resistance breeding for organic apple production until 2015, but then the funding for the activities was cut. The resulting cultivars have found acceptance among producers as they reduce costs.

Breeding goals

For apples, the main breeding goals are size, shape, colour, taste (rather sweet or rather acidic), quality of the skin, firmness and juiciness of fruit, scab resistance and shelf life. Most of these breeding goals are similar for organic and conventional apple breeding. Certain diseases like fire blight and Marssonina leaf drop are only relevant in certain regions. In German apple breeding, the focus used to be on monogenic resistances, e.g. the resistance gene RW6 /VF against apple scab or a resistance against Marssonina blotch. However, since these resistances have been broken in "Topaz", which used to be the most prevalent apple cultivar in organic production in Midwest Europe. Organic breeding programmes have a strong focus towards breeding for general robustness against a wide range of diseases and pest. Organic apple nurseries also rely on different root stock genetics which influences tree growth and resistance traits compared to conventional apple production as chemical thinning is not allowed in organic production.

Hungarian apple breeding goals are multi-resistances against scab, powdery mildew, etc., to make the cultivars suitable for organic cultivation. Some cultivars have been bred by a Hungarian university breeder.

Technical, regulatory and market challenges

Apple breeding takes very long, about 20 to 25 years. There is only a very small percent of characteristics of the parental lines that are passed on to the progeny (around 5%). This makes the breeding outcome somewhat unpredictable. Additionally, in biodynamic breeding, some breeding techniques are excluded. This makes it cheaper on the one hand, but less certain to be successful and therefore more time intensive in the long run. Furthermore, bringing a variety to market and getting it accepted by apple growers is always a challenge. Several apple varieties are known to the consumers, and cultivars with new names are not necessarily bought. Further, apple varieties (including club varieties) are very highly promoted in the conventional market. This is not possible with a small budget like e.g. the Swiss organic apple breeding initiative that is mostly funded by private donors.

Apart from general challenges, some interview partners mentioned some specific aspects from their countries. In Hungary, there is no organic rootstock available, because the tree nurseries use chemical fertilizers to accelerate the breeding process. Also, some chemical pest/disease control is mandatory making it impossible to breeding entirely under organic conditions.

An organic apple producer association with some organic breeding activities in Germany specifically mentioned that getting access to genetic material is difficult, as club varieties are very common for apples. Here, only club members can use a variety. It takes time and trust building to overcome this obstacle. However, associations took up their own breeding activities to become independent of this system.

Financial considerations

For apples, the conventional way to finance breeding is often through so-called club cultivars. Here the whole value chain is connected and exclusive. Cultivars are bred and licensed out to a specific chain of actors (tree nurseries, apple producers, traders, and supermarkets). A license is paid per tree by the growers as well as per kg of apples sold which covers also the marketing costs. Only club members can access the cultivars. Cultivar bred by a publicly funded organisation can also become a club cultivar under a different name, but have to also be publicly available.

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In Hungary, the breeding costs are recovered through a more traditional licensing and re-financing model. The breeder produces a variety first, and only then makes a contract with a tree nursery that propagates the variety. The tree nursery pays an agreed amount of money as a licence fee for each variety, which can vary from one variety to another. This is the most common model at present, which is considered to be working very well in conventional (non-organic) apple breeding. Historically, there used to be public funding for apple breeding, but this has been drastically cut in the last years. Hungarian breeders and seed producers active in the organic sector recommend a pre-financing of breeding by value chain actors in order to boost organic breeding. They argue that a pre-financing model would be much more promising, because there is not enough organic area for re-financing. A public-private cooperation financing breeding and seed production could make a "breakthrough" in the whole sector. One former breeder stressed that establishing pre-financing is challenging, but a combination of 60% pre-financing coverage of breeding costs and 40% through breeders' right payments and licence fees could work well in her experience.

The breeding activities of the organic apple association in Germany are financed by its members and through an EIP- AGRI innovation grant. They suggest that re-financing through licenses will be part of the financing for breeding in the long term, but that also other sources such as public funding and value chain funding will probably be needed, since especially for fruits, the process of breeding is so long. However, they doubt that enough financial means can be acquired through the traders etc. to finance fruit breeding for the organic sector, but seeking financial support from the supply chain would help to create some awareness about the need for breeding and limited access to suitable cultivars. The association argues that having adapted cultivars is in the public interest which justifies public funding, even if funds have been cut in recent years.

The public research and agrarian services centre in the North of Spain receives public support for apple breeding, but also sells propagation material to farmers, so breeding activities are partly publicly funded and partly re-financed. This mixture works well for them.

5.3 Forage crops

5.3.1 General

Main actors and stages

The only European breeding programmes for organic farming in the forage sector we were able to identify are conducted by the public sector research organisation Agroscope in Switzerland. In these programmes the choice of the components of a new variety (row sowings) and the testing of the breeding lines take place on fields managed according to organic farming conditions to ensure that only those plants and breeding lines that are ideally adapted to organic-farming conditions prevail. The programmes include both clover and grass species. The goals of the programmes focus on disease resistance, competitiveness against weeds, high yields at with low nitrogen inputs.

The financing model of this specific case is based on a partnership between the research institute and a small-medium seed company, where Agroscope is responsible for the fundamental breeding work, and the company for the registration into the national variety list and the basic seed production. Public funding and revenues from royalties constitute the basis of the breeding and registration of varieties. The seed of the most suitable varieties is multiplied under organic conditions and commercialised (see Figure 16). Similar financing approaches are found in other countries and research organisations (for example Aberystwyth University in the United Kingdom and ILVO in Belgium) undertaking breeding of forage crops but not specifically concerned with breeding for organic farming.

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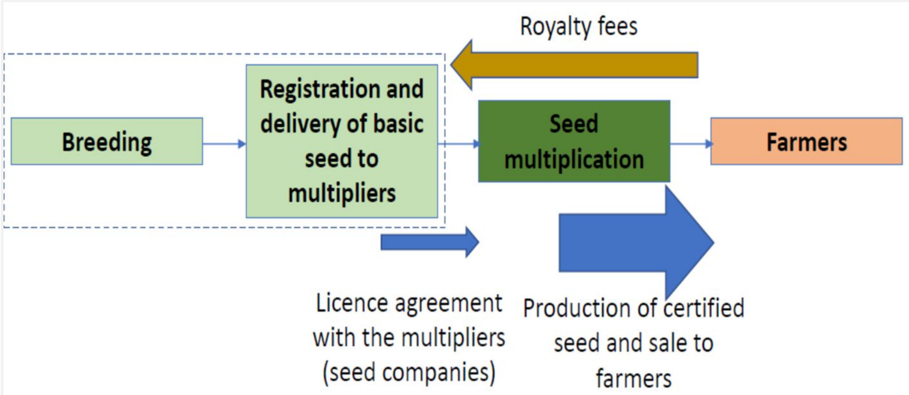
Figure 16: Typical business and supply chain model of breeding for the forage sector



Source: Wilhem (2016) adapted

The following two financing models for breeding are found within the forage sector:

- Private-public partnership where a public breeding institute undertakes the breeding and a private seed company is in charge of the variety registration and seed multiplication. Public financing and royalties from seed sales fund the breeding programmes. This mechanism is used by Agroscope to breed forages for organic farming, as well as by other public breeding institutes to fund conventional breeding.
- A few multinational seed companies fund their own (conventional) breeding programmes for forage through seed sales. This is the case of the conventional breeding activities carried out for the most common species (in particular perennial ryegrass, white clover, red clover) which have the biggest market share within the forage sector.

Breeding goals

Apart from Agroscrope in Switzerland, no other dedicated organic breeding programmes for organic in the forage sector were identified. Companies explained this by arguing that the breeding goals of conventional and organic breeding are indeed very similar. This confirms the results of a previous survey carried out by Baert et al. (2006) with 10 forage breeders in the Netherlands, Germany, France, United Kingdom, Switzerland and Belgium who contended that the best varieties for conventional farming are also the most suitable for organic farming.

The most important traits by which potential forage varieties are assessed are dry-matter yield, protein content, nutrient use efficiency (for grasses), and persistency in the sward (especially for clover). Given the difficulties in forage seed multiplication explained (see Section 4.3) companies also consider seed yield as very important and conduct trials to ensure that seed production can be done in an economically sustainable way. Disease and pest resistance and abiotic stress tolerance are also common goals.

The next subsections provide some key information on breeding for perennial ryegrass and white clover – mainly carried out in Northern and European countries – and on alfalfa, mainly carried out in the Mediterranean countries

5.3.2 Perennial ryegrass

Perennial ryegrass breeding includes both diploid and tetraploid variety production in medium and late flowering categories. The companies that we interviewed undertaking grass breeding focus on

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varieties at the top level of dry matter yield, persistence, disease resistance, winter hardiness, sward density, drought tolerance and seed yield.

In recent years the issue of nitrogen use efficiency has become of increasing interest, both for conventional and organic farms. The protein content of ryegrass varieties often exceeds the requirements of a grazing animal, and the ratio of water-soluble carbohydrate (WSC) to protein is too low for efficient protein utilisation, resulting in poor nitrogen use efficiency (NUE) in the farming system by livestock (Baert et al. 2006; Pembleton et al. 2016). This is relevant both to intensive livestock as well as low-input and organic farms, as feeding ryegrasses with higher WSC content improves annual dry matter yield under nitrogen limiting conditions by improving rumen efficiency allowing increased protein synthesis (Baert et al. 2006; Pembleton et al. 2016). Seed companies as well as research centres in Germany, Denmark, the United Kingdom have invested over the last ten years in developing the so called 'high sugar grass' varieties which perform well with less nitrogen fertiliser and make better use of available nitrogen from clover. These varieties are not available as organic seed as the results so far in organic seed multiplication have not been satisfactory.

5.3.3 White clover

White clover-grass mixtures normally produce less biomass than grasses but better forage quality and require less nitrogen (due to biological nitrogen fixation), no weed control and no pesticide application (Annicchiarico 2003). The main breeding goals of the companies interviewed are persistency, early spring growth which is a priority for both organic and conventional farmers, tolerance to biotic and abiotic stress.

Whereas red clover is mainly trialled in pure stand, most of the breeding trials for white clover in the United Kingdom are done in a mixture of grass and clover in order to select for the white clover lines for the best match with the grass. This is because white clover suffers from competitive ability relative to grass companions, at the expense of the overall forage quality (including nutritional value and palatability). These variety trials are however conducted only in conventional systems.

5.3.4 Lucerne (alfalfa)

The interviewed experts and companies stated that there is no need for breeding programmes for alfalfa for organic farming. Like white clover, lucerne is commonly grown under low nitrogen input conditions both in conventional and organic farming. Breeding goals remain high yields, resistance to diseases and competitive ability against weeds.

A study conducted by Annicchiarico and Pecetti (2010) in Italy, evaluated different varieties under a chemically weeded management and an organic management with no chemical weed control. The research conclusion was that variety adaptation of lucerne to organic conditions depend on specific adaptation to the region rather than on selection under organic conditions. In fact the consistency of variety dry matter yield as well as seed yield responses across management imply that there is no need to perform breeding for organic farming for lucerne. This study is amongst the very few found specifically investigating on an empirical basis the issue of the need for organic breeding for a forage crop. However, it must also be pointed out that more empirical evidence is needed for situations where other factors such as tolerance to major biotic stresses are considered and which might result important for adaptation of alfalfa (and forage crops in general) to organic farming conditions.

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6 Conclusions

The aim of this report was to understand the state of organic seed use, seed production and breeding in Europe in the different sectors of combinable arable crops (e.g. cereals and pulses and oilseeds), horticultural crops (e.g. vegetables and fruit) and forage crops (e.g. clovers and grasses). In the following we have set out some key observations comparing the different sectors, crops and regions of Europe.

The question of organic seed use and organic breeding are often treated and discussed together. However it is important to remember that at present the organic regulation requires the use of seed multiplied under organic conditions (at present allowing derogations), whereas the use of organic cultivars is not mandatory. Our research indicates that the choice of suitable organic varieties emerges as one of the strongest motives for farmers to use organic seed and the lack of seed for suitable varieties is a strong barrier to organic seed use.

Across the sectors, our research indicates that there is substantial gap between the organic seed offer and demand in all sectors, although the lack of data on the actual non-organic seed use relative to the organic land area for specific crops makes it difficult to come to firm conclusions.

6.1 General trends and observations

All three sectors have in common that they are characterised by substantial increase in the organic land area in the last decade, leading to increased demand for organic seed. However, Solfanelli et al. (2019) indicate that for most crops and in all regions of the EU untreated conventional seed is still commonly used although some differences can be observed (Table 12). Non-organic seed use is highest for some forage crops and in the South and East of Europe, whereas for certain cereals and vegetables in Central Europe non-organic seed use below 25% was reported. For the focus crop of carrots experts estimated that about 90% of the seed is from conventionally multiplied and conventionally bred cultivars.

The farmer survey of LIVESEED indicated differences in organic seed use between the sectors and the regions of the EU. The highest share of organic seed use was reported for farms that predominately grow vegetables, whereas the lowest share was found for forage farmers. Organic propagation material use in fruit farms was significantly lower than for arable and forage farms. Farms in Northern and Central Europe had significantly higher use of organic seed than in Southern Europe, which in turn had significantly higher organic seed use than Eastern Europe.

Table 11: Average use of untreated conventional seed according in the different crop sectors and regions of the EU (in % of total seed use)*

	Arable Crops	Vegetables	Fruits	Forage crops
Central Europe	16 (10-25)	14 (10-21)	38 (10-71)	29 (18-50)
East	39 (21-64)	37 (21-59)	69 (46-100)	55 (49-61)
North	40 (15-67)	32 (21-45)	30 (21-40)	36 (16-55)
South	30 (17-44)	18 (13-22)	57 (53-61)	57 (31-90)

*Average values for crops in the category shown with min and max values in brackets.

Source: Table 9 from Orsini et al., 2019

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The comparison of derogations between 2004 and 2014 to 2016 for selected crops has shown that the volume of seed and number of derogations have increased in most cases. This goes alongside a substantial increase in land area. Increases in land area are likely to continue, as several countries have growth targets for organic agriculture which will lead to additional demand for organic seed.

6.2 Regulatory issues

According to the literature and some of the experts that we interviewed, the present derogation system has not encouraged the development of the organic seed sector (e.g. Döring et al. 2012; Le Doaré, 2017; Pedersen and Rey, 2016). The lack of effectiveness of the derogation regime is also suggested by the long-term trend in derogation in the three crop sectors.

The regulatory regime foresees that countries can have National Annexes of crops for which sufficient organic seed is available and derogations for the use of non-organic seed can no longer be obtained (Category 1). Five EU Member States in Central Europe (Belgium, Netherlands, Luxembourg, France Germany), one country in the North (Sweden) and Switzerland have developed National Annexes to the organic regulation for seed, listing crops for which derogations for the use of non-organic seed can no longer be granted, but the crop species vary between countries. No country in the South or East have crops species listed in Category 1.

Crops from all three sectors can be found on some Category 1 list. The crops most often listed are onions in six countries, followed by oats, grain maize, cucumber, pumpkin, beans, endive and radish in five countries, soft winter wheat, spelt, triticale and rye as well as cress and vetch in four countries. The picture may change over time, because category lists are updated regularly to reflect the changing availability of organic seed.

The farmer survey found crops placed in Category 1 in some countries are amongst those with the highest share of organic seed use across EU countries.

For the focus crop of durum wheat, the experts from Italy considered the continuation of the derogation regime as necessary, despite an increased offer of organic seed.

For carrots, experts in Denmark and France reported regulatory efforts of an agreed organic seed percentage. In Denmark, this did not result in increase in the organic seed offer. In France, this measure was taken in 2018, aiming for 40%, 66% and 100% organic carrot seed on farm level in 2019, 2020 and 2021, respectively.

However, the likely increase in demand from increases in land area make it questionable whether the derogation regime alone is sufficient to achieve lasting improvements to organic seed use in Europe.

6.3 Organic seed multiplication

6.3.1 Main actors

The organic arable seed sector is characterised by small to medium companies that multiply organic seed and sell through retailers or direct to famers. Supply chain integration is common, and seed production may be outsourced to farmers or farmers' cooperatives. Both conventional and organically bred cultivars are multiplied by most companies, but some specialise only in organic varieties. The majority of companies are located in Central Europe, whereas farmers in Eastern Europe depend mostly on imported organic seed. In the South, some initiatives exist and the informal seed system is

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important, even if the amount of seed exchanged are estimated to be small, compared with the total organic seed market.

In the vegetable sector, a high level of integration between breeding and seed multiplication was observed, with larger companies producing seed from their own cultivars and breeding activities. Most companies and initiatives working with organic seed of vegetables and fruit are situated in Central Europe, but some initiatives are also found in the South and South-West. Organic seed multiplication in Eastern Europe appears to be very limited.

Organic seed production for forage crops mainly occurs in Central and Northern Europe, with the only exception for lucerne which is multiplied for organic seed production mostly in Italy and France. In the forage sector interaction in the supply chain appear to only take place between seed companies and farmers, in contrast to the other crop sectors, where examples of interaction and integration between the seed multiplication stage, and the market actors of the whole food chain (such as processors and retailers as well) were identified.

6.3.2 Technical challenges

Notwithstanding the positive trend in the organic seed sector, there are still many factors which limit and hinder the development of the organic seed market of arable crops in the EU. Annual increases in the number and volumes of derogations, granted for non-organic arable seed use, clearly indicate that the seed sector is not growing fast enough to keep up with the growth of the organic area. According to the interviews with seed multipliers and experts, organic seed supply is reaching satisfactory levels in Central European Countries. High levels of supply for soft organic wheat varieties were registered in Austria, Denmark, France, Germany, and Switzerland. However, in the Southern and Eastern Member States the producers of arable crops mostly rely on untreated conventional seed that requires derogation. Among the countries investigated, the supply of organic varieties of wheat seems to be very limited in Italy (i.e. the highest rate of use of non-organic seeds), Romania, Lithuania, and Greece.

In general, organic wheat seed is more expensive to produce than conventional. Lower yields can occur due to both weed and disease impacts. Organic seed producers of wheat consider the lack of treatments for common bunt and other diseases a major challenge, although this may also be related to lack of knowhow how to use existing treatments effectively. Also weed contamination of seed is seen as challenging. This implies the need for investment in separate seed cleaning (including brushes to treat some diseases) and storage facilities for companies wanting to engage. Some success has been achieved with strategies to improve the spatial distribution of seed and with that the competition against weeds. Many seed suppliers reported problems in finding farmers willing to multiply seed crops under organic conditions. Overall at least for wheat there seems to be a good supply of organic seed in Central Europe. This is not the case for the two vegetable crops.

Vegetable seed production requires specific climatic conditions and know-how, and is carried out globally, often not in the countries where the crops are produced. For some crops the seed is produced indoors in greenhouses. Pest and disease control and yield reduction were reported as the most important technical challenge of organic seed multiplication, with some differences in seed production of conventional and organically bred varieties. Less seed multiplication activities were identified for carrots than for cauliflower. Carrot is a technically particularly challenging seed crop with pest and disease risk for which not enough organic alternative treatments have been developed. The interviewees reported substantial technical challenges in the outdoor multiplication of carrot seed with pest (lygus beetle) and disease (alternaria) problems leading to frequent seed crop failure or low seed quality. For cauliflower, organic multiplication seems less challenging, as it can be done in

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greenhouses and poly tunnels. As a result, the price difference between organic and conventional seed is moderate and appears to be tolerable for organic cauliflower producers. However, organic seed availability of cauliflower remains not sufficient and the crop has not yet been included in the Category 1 in any country. Moreover, the number of cell fusion-free cultivars is very limited for cauliflower.

Apple transplant production is challenging too. Organic scions and rootstocks are more difficult to obtain in organic apple production. Investment in pest and disease management under organic conditions at rootstock, scion and transplant level are needed if the availability of good quality organic propagation material for apples has to increase.

In the forage sector, grasses and small seeded legumes have different challenges in the organic seed multiplication. For white clover and lucerne (alfalfa) the main issue is represented by weed contamination and the costs required for cleaning the very small seed from weeds. For perennial ryegrass the challenge is to provide adequate nutrient supply, especially nitrogen (considering that species and varieties are multiplied in pure stand). Overall, both weed control for legumes and nitrogen provisions for grasses can be improved through the crop rotation in the years between seed crops. The trend in derogation does not suggest a decrease for the key crops, i.e. ryegrass, clover and fescue. Also the seed companies interviewed did not report a decrease in derogation per farm, although they have increased their market share of organic seed for forage crops as a consequence of more land being organically farmed.

A specific challenge to increase the use of organic seed is related to forage crops being grown in mixtures. Particularly in organic farming, mixtures should be diverse, containing different species and varieties. This makes it difficult to find organic seed for all the crop species and varieties needed. The interviewees consistently reported a trade-off between selling the organic mixture on the one hand, and selling diversified, suitable mixture on the other hand. For such reasons, the seed companies argued that adopting a 70% threshold rather than the more stringent 100% rule for the mixture would be their preferred, allowing more room for manoeuvre in adjusting and tailoring the mix to the needs of the organic farms.

6.4 Organic breeding

6.4.1 Arable breeding

Organic breeders are unanimous about the need to develop specific breeding programs for organic durum and soft wheat. However, these are limited by two main factors. Firstly, the low return on investment of dedicated organic breeding programs, which is strongly related to the small size of the organic market. Secondly, there is a lack of organic VCU procedures for variety testing under organic conditions. These exist only in a few EU countries and mainly for soft wheat (see Kovacs and Pedersen 2019).

Some conventional breeders have considered minor adjustments to their breeding goals in order to develop varieties suitable to both conventional and organic farming conditions. This approach would allow to cover a larger potential market, which may ensure a higher return on investment of the breeding programs.

Unlike wheat, there are not substantial differences in breeding goals between conventional and organic lupine. The narrow base of genetic diversity is the main limitation faced by both conventional and organic breeders.

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Overall, we observed that there is an increasing number of Participatory Plant Breeding (PPB) projects for organic cereals in Europe. These breeding initiatives, which are often associated with conservation breeding and evolutionary breeding methods, represent only a minor part of the total European organic seed market. However, they contribute to the development of an alternative strategy for the production and distribution of organic seed. In the near future, the new organic regulation (EU) 2018/848 coming into force in 2021 grants also the commercialization of organic heterogeneous material with high level of genetic and phenotypic diversity without DUS and VCU requirements.
Also, the analysis of specific initiatives has shown that in order to encourage breeders to select varieties for organic farming, it is important to develop collaborative relationship between different players of the organic value chain. Collaborative relationships can help breeders deal with supply and demand uncertainties as well as achieve revenue enhancement.

6.4.2 Vegetable breeding

In the vegetable sector, the organic breeders who also multiply seed only work with organic cultivars, which is different to the arable sector who multiply seed both conventionally and organically. In countries in Central Europe (DE, CH, FR, NL) two contrasting trends can be observed in vegetable breeding activities. The global trend of concentration in vegetable breeding results in companies investing mainly in the breeding of crops that are expected to be profitable. Actors working with these companies see no need for special breeding activities for organic farming. In contrast, there are a number of mainly smaller companies and/or initiatives involving farmers, which work with a wider range of crops and mostly with open pollinated cultivars for organic.

In Italy, Spain and Portugal only a small number of organic breeding initiatives were identified and there is almost not such activity in the South East Europe with the exception of breeding of multi-resistant apple varieties in Hungary.

Breeding activities exclusively for the organic sector by private companies have partly developed in response to dominance of F1 hybrids, and cultivars bred with cell fusion in the conventional market making breeding techniques a major point of departure.

From the interviews it emerged there seems not to be agreement among experts and companies as to whether organic and conventional breeding programmes have the same or substantially different breeding goals. Moreover, most existing breeding initiatives for organic cauliflower, carrot and apple production have fragmented and insecure funding. There is a consensus that with the current organic market size, organic breeding activities cannot be entirely re-financed through seed sales.

To improve the current situation, most interviewees support a public- private cooperation. A value chain-based pre-financing model is also deemed as a promising approach for all three crops investigated in the case studies. Also, since fruit and vegetable are often consumed fresh and there is an “emotional” relationship with consumers, communication strategies can be developed in order to re-finance breeding activities with the help of consumers. Some successful examples have been found and described in this research report.

6.4.3 Forage

Breeding for organic farming conditions is far less developed for forage than for the other crop sectors. The only breeding programmes for both ryegrass and clover is undertaken by Agroscope in Switzerland, which works in a public private partnership with a seed company responsible for the registration and the seed production. Public funding and royalties fund the programmes. This is also the most common financing model for conventional breeding for this sector. Another model is

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represented by the multinational companies undertaking (conventional) breeding for the most commonly used species (ryegrass and clover). Therefore, the breeding funding mechanisms are much less diversified than in the arable, vegetable and fruit sectors.

The stakeholders interviewed argued that there is not a specific need for breeding for organic forage crops, as the goals are similar, i.e. improved nitrogen efficiency use in grasses, and crop persistency, resistance to biotic and abiotic stress, and overall forage quality for clovers and grasses. This is confirmed by a previous similar survey conducted with breeders in Europe by Baert et al. (2007). Farmers who participated in the LIVESEED online survey also ranked the need for organic breeding for forage crops as of 'average importance', compared to 'very high importance' for most crops in the other crop sectors.

The conclusion according to the stakeholder consultation undertaken in this case study research is that in the forage sector it should be possible to breed in the conventional way for organic farming, considering the specific goals. A good case is the sugar in grasses, leading to varieties with a lower N content and need, better N utilisation by the grazing animals and lower N loss to the environment. However, more empirical evidence is needed by testing varieties bred in conventional and organic in mixtures (rather than pure stand) under a wide range of management systems.

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7 References

Abraham, E. M., Ganopoulos, I., Madesis, P., Mavromatis, A., Mylona, P., Nianiou-Obeidat, I Parissi, Z., Polidoros, A., Tani, E., Vlachostergios, D. (2019). The use of lupin as a source of protein in animal feeding: Genomic tools and breeding approaches. International Journal of Molecular Sciences, 20(4). https://doi.org/10.3390/ijms20040851

Adhikari, K., Buirchell, B., & Stefanova, K. (2005). The level of natural outcrossing and isolation distance in yellow lupins Outcrossing and isolation distance in yellow lupins, (April 2016).

Annicchiarico, P. (2003). Breeding white clover for increased ability to compete with associated grasses. *The Journal of Agricultural Science*, 140(3), 255-266.

Atkinson, D., Watson, C. (Eds.). (2019). The science beneath organic production. John Wiley & Sons.

Australian Government. (2013). The biology of Lupinus L. (lupin or lupine) (1st ed.). Australian Government, Department of Health and Ageing, Office of the Gene Technology Regulator.

Baert, J., Eekeren, N.V., Ghesquiere, A. (2007). Breeding fodder grass and clover for low input/organic conditions in NW Europe. In: *Breeding and seed production for conventional and organic agriculture. Proceedings of the XXVI meeting of the EUCARPIA fodder crops and amenity grasses section*. XVI Meeting of the EUCARPIA Medicago spp Group, Perugia, Italy, 2-7 September 2006 (pp. 31-37).

Bioaktuell, 2019. Saat- und Pflanzgut- Das Wichtigste in Kürze. Lenkungsabgaben https://www.bioaktuell.ch/pflanzenbau/biosaatgut/das-wichtigste-in-kuerze.html

Boelt, B. (2003). Organic forage seed production. In Proceedings Fifth International Herbage Seed Conference, Gatton, Australia, 23-26 November 2003. Herbage Seeds in the New Millenium-New Markets, New Products, New Opportunities, pp. 43-47.

British Grassland Society (2019). Recommended grass and clover lists for England and Wales 2019/2020. BGS Cheshire.

Brophy, C., Finn, J. A., Lüscher, A., Suter, M., Kirwan, L., Sebastià, M. T., ... Collins, R. P. (2017). Major shifts in species' relative abundance in grassland mixtures alongside positive effects of species diversity in yield: a continental-scale experiment. *Journal of Ecology*, 105(5): 1210-1222.

Ceccarelli, S., Grando, S. (2007). Decentralized-participatory plant breeding: An example of demand driven research. *Euphytica,* 155(3):349–360. https://doi.org/10.1007/s10681-006-9336-8

Cheatham, M., Rouse, M., Esker, P., Ignacio, S., Pradel, W., Raymundo, R., Sparks, A., Forbes, G., Gordon, T., Garrett, K., 2009. Beyond Yield: Plant Disease in the Context of Ecosystem Services. *Phytopathology* 99: 1228-1236.

Collard, B. C. Y., Jahufer, M. Z. Z., Brouwer, J. B., & Pang, E. C. K. (2005). An introduction to markers, quantitative trait loci (QTL) mapping and marker-assisted selection for crop improvement: The basic concepts. *Euphytica,* 142(1–2): 169–196. https://doi.org/10.1007/s10681-005-1681-5

De Vita, P., Colecchia, S. A., Pecorella, I., & Saia, S. (2017). Reduced inter-row distance improves yield and competition against weeds in a semi-dwarf durum wheat variety. *European Journal of Agronomy*, 85:69–77. https://doi.org/10.1016/j.eja.2017.02.003

De Vita, P., Nicosia, O. L. D., Nigro, F., Platani, C., Riefolo, C., Di Fonzo, N., & Cattivelli, L. (2007). Breeding progress in morpho-physiological, agronomical and qualitative traits of durum wheat cultivars released in Italy during the 20th century. *European Journal of Agronomy*, 26(1):39–53. https://doi.org/10.1016/j.eja.2006.08.009

LIVESEED is funded by the European Union's Horizon 2020 under grant agreement No 727230 and by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00090.

Defra (2003). Development of grass and white clover variety testing systems to predict performance under conventional, low-input and organic livestock production. London, UK.

De Santis, Michele A., Marcella M. Giuliani, Luigia Giuzio, Pasquale De Vita, Alison Lovegrove, Peter R. Shewry, and Zina Flagella. (2017). Differences in Gluten Protein Composition between Old and Modern Durum Wheat Genotypes in Relation to 20th Century Breeding in Italy. *European Journal of Agronomy,* 87, 19-29

Dinelli, G., Marotti, I., Di Silvestro, R., Bosi, S., Bregola, V., Accorsi, M., Di Loreto, A., Benedettelli, S., Ghiselli, L., Catizonel, P. (2013). Agronomic, nutritional and nutraceutical aspects of durum wheat (Triticum durum Desf.) cultivars under low input agricultural management. *Italian Journal of Agronomy*, 8(2): 85–93. https://doi.org/10.4081/ija.2013.e12

Döring, T.F., Bocci, R., Hitchings, R., Howlett, S., Lammerts van Bueren, E.T., Pautasso, M., Raaijmakers, M., Rey, F., Stubsgaard, A., Weinhappel, M., Wilbois, K.P., Winkler, L.R., Wolfe, M.S., 2012. The organic seed regulations framework in Europe. *Organic Agriculture,* 2:173-183.

European Commission (2018). Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on Organic Production and Labelling of Organic Products and Repealing Council Regulation (EC) No 834/2007

Elsen, A.V., Ayerdi Gotor, A., di Vicente, C., Traon, D., Gennatas, J., Amat, L., Negri, V., Chable, V., (2013). Plant breeding for an EU bio-based economy.: The potential of public sector and public/private partnerships. Plant breeding for an EU bio-based economy. Publications Office of the European Union: 2-157. Brussles

EUROSTAT, 2019. The fruit and vegetable sector in the EU - a statistical overview https://ec.europa.eu/eurostat/statistics-explained/index.php/

Geier, U., 2013. Möhren und Geschmack - Auf die Sorte kommt es an Ernährung im Fokus. Lebendige Erde. 5: 36-39.

Gislum, R., Jensen, E. S., Boelt, B., Wollenweber, B. (2003). Intercropped green manure legumes in perennial ryegrass (*Lolium perenne* L.) for seed production. In: Dynamics of Nitrogen Use Efficiency in Grass Seed Crops. Ph.D. Disssertation. The royal Veterinary and Agricultural University, Copenhagen.

Groot, S., Jalink, H., Hospers-Brands, A., Köhl, J., Veerman, A., Wenneker, M., Wolf, G.A., Bulk, van den Bulk, R. (2006). Improvement of the quality of propagation material for organic farming system. In: Proceedings of the European Joint Organic Congress, Odense, Denmark, 30-31 May 2006. - Odense, Denmark.

Groot, S.P., Van der Wolf, J.M., Jalink, H., Langerak, C.J., van den Bulk, R.W.(2005). Challenges for the production of high-quality organic seeds. *Seed Testing International,* 127: 12-15.

Haesen, Esther. *Efficacy of non-synthetic seed treatments against anthracnose (Colletotrichum lupini) in white lupin*. Doctoral Dissertation, Research Institute of Organic Agriculture (FiBL), CH-Frick ETH Zurich, CH-Zurich, 2018.

Hammond, K.J., Humphries, D.J., Westbury, D.B., Thomson, A., Crompton, L.A., Kirton, P., Green, C. & Reynolds, C.K. (2014). The inclusion of forage mixtures in the diet of growing dairy heifers: Impacts on digestion, energy utilisation, and methane emissions. *Agriculture Ecosystems & Environment*, 197:88-95.

Herstatt, M. (2017). Economic Analysis of Different Seed Value Chains for Organic Carrot Production. Master Thesis, KU Leuven.

LIVESEED is funded by the European Union's Horizon 2020 under grant agreement No 727230 and by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00090.

Hubbard, K. & Zystro, J. (2016). State of Organic Seed, 2016. Organic Seed Alliance, US.

Köhl, J., Van Tongeren, C., Groenenboom-de Haas, B., Van Hoof, R., Driessen, R., Van Der Heijden, L., (2010). Epidemiology of dark leaf spot caused by Alternaria brassicicola and A. brassicae in organic seed production of cauliflower. *Plant pathology* 59: 358-367.

Koller, M. (2017) Organic vegetable expert, personal communication.

Kotschi, J., Wirz, J. (2015) Who pays for seeds? Thoughts on financing organic plant breeding. Working Paper. AGRECOL and Section for Agriculture. Marburg and Dornach. https://www.opensourceseeds.org/sites/default/files/downloads/Who_pays_for_seeds.pdfKovács, T., Mariegaard Pedersen, T. (2019). Deliverable 2.1: Overview on the current organizational models for cultivar testing for Organic Agriculture over some EU countries, (May), 84. Retrieved from https://www.liveseed.eu/wp-content/uploads/2019/07/LIVESEED_D2.1_Overview-of-the-organisational-models-of-cultivar-trials-for-organic-agriculture.pdf

Lammerts van Bueren, E. T., Wilbois, K.-P., Østergård, H. (2007). European perspectives of organic plant breeding and seed production in a genomics era. *Journal of Agriculture and Rural Development in the Tropics and Suptropics*, 89: 101–120.

Lammerts van Bueren, E.T., Jones, S.S., Tamm L., Murphy, K.M., Myers J.R., Leifert, C., Messmer M.M. (2011) The need to breed crop varieties suitable for organic farming, using wheat, tomato and broccoli as examples: A review. NJAS - Wageningen J. Life Sci. 580:193–205.

Lammerts van Bueren, E.T., Struik, P.C., van Eekeren, N., Nuijten, E. (2018) Towards resilience through systems-based plant breeding. A review. Agron. Sustain. Dev. 38 : 42 doi:10.1007/s13593-018-0522-6.

Le Doaré, N. (2017). Les producteurs de légumes bio bretons face à leurs semences et variétés: Quelles pratiques, quels déterminants? Master thesis, AgroParisTech, Université Paris Saclay.

Levert, M. (2014). The market for organic and ecological seed in Canada. Canada Organic Trade Association, Canada.

Li, G., Kemp, P.D. (2005). Forage chicory (Cichorium intybus L.): a review of its agronomy and animal production. *Advances in agronomy*, 88: 187-222.

Lucas, M. M., Stoddard, F. L., Annicchiarico, P., Frías, J., Martínez-Villaluenga, C., Sussmann, D., Duranti, M., Seger, A., Zander, P. M., Pueyo, J. J. (2015). The future of lupin as a protein crop in Europe. *Frontiers in Plant Science*, 6: 705. http://doi.org/10.3389/fpls.2015.00705

Luescher, A., Mueller-Harvey, I., Soussana, J.F., Rees, R.M. & Peyraud, J.L. (2014). Potential of legume-based grassland-livestock systems in Europe: a review. *Grass and Forage Science*, 69:206-228.

Micheloni, C., Plakolm, G., Schärer, H., Bertelsen, J., Roviglioni, R., Lammerts van Bueren, E., & Fromm, E. (2007). Report on seed borne diseases in organic seed and propagation material. Research to support the revision of the EU Regulation on organic agriculture. Project Deliverable Research to support the revision of the EU Regulation on organic agriculture. Brussels

Miedaner, T., 2018. Züchten die Ökos anders? , DLG Mitteilungen. Deutsche Gesellschaft für Landwirtschaft.

Morris, M. L., & Bellon, M. R. (2004). Participatory plant breeding research: Opportunities and challenges for the international crop improvement system. *Euphytica*, 136(1): 21–35. https://doi.org/10.1023/B:EUPH.0000019509.37769.b1

LIVESEED is funded by the European Union's Horizon 2020 under grant agreement No 727230 and by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00090.

Naspetti, S., Lampkin, N., Nicolas, P., Stolze, M., & Zanoli, R. (2011). Organic supply chain collaboration: A case study in eight EU countries. *Journal of Food Products Marketing,* 17: 141-162). https://doi.org/10.1080/10454446.2011.548733

Naturata International, 2015. Beitrag zur Sicherung des qualitätsorientierten Bio-Gemüsesortiments. https://www.naturata-verein.de/wpcontent/uploads/Presserklaerung.NATURATA_Mar2015_2.pdf, press release

Orsini, S., Padel, S., Solfanelli, F., Costanzo, A., Zanoli, R. (2019). Report on the relative importance of different factors encouraging farmers to use/ not use organic seed in organic supply chains. LIVESEED Deliverable D4.1. https://www.liveseed.eu/wp-content/uploads/2019/09/LIVESEED-D4.1-Report-on-relative-importance-of-factors-encouraging-or-discouraging-farmers-to-use-organic-seed-in-organic-supply-chains.Cpdf_.pdf

Osman, A. M., Almekinders, C. J. M., Struik, P. C., & Lammerts van Bueren, E. T. (2016). Adapting spring wheat breeding to the needs of the organic sector. *NJAS - Wageningen Journal of Life Sciences*, 76: 55–63. https://doi.org/10.1016/j.njas.2015.11.004

Osman, A. M., Almekinders, C. J. M., Struik, P. C., & Lammerts Van Bueren, E. T. (2008). Can conventional breeding programmes provide onion varieties that are suitable for organic farming in the Netherlands? *Euphytica,* 163(3): 511–522. https://doi.org/10.1007/s10681-008-9700-y

Osman, A. M., K. J. Muller, and K. P. Wilbois, eds. 2007. Proceedings of the ECO-PB International Workshop on Different Models to Finance Plant Breeding. Frankfurt, Germany. https://www.eco-pb.org/fileadmin/eco-pb/documents/reports_proceedings/proceedings_070227.pdf

Pedersen, T. M. (2012). Organic VCU testing. Current status in 16 European countries. Knowledge Centre for Agriculture, Denmark

Pedersen, T., Rey, F., 2016. Breeding for diversity – political implications and pathways for the future. In: ITAB, France (Ed.) https://orgprints.org/31147/1/Cobra_net.pdf

Pembleton, L.W., Wang, J., Spangenberg, G.C., Forster, J.W., Cogan, N.O.I. (2016). Low-cost automated biochemical phenotyping for optimised nutrient quality components in ryegrass breeding. *Crop and Pasture Science*, 67(8): 888-896.

Quelles pratiques, quels déterminants? . Master thesis, AgroParisTech, Université Paris Saclay.

Raaijmakers, M., & Schäfer, F. (2019). Report on Political Obstacles and Bottlenecks on the Implementation of the Rules for Organic Seed in the Organic Regulation. LIVESEED Deliverable 1.9 https://www.liveseed.eu/wp-content/uploads/2019/10/LIVESEED_D1.9_M1.9_Political_Obstacle_Report_FINAB.pdf

Renaud, E.N., Bueren, E.T.L.V., Jiggins, J., 2016. The meta-governance of organic seed regulation in the USA, European Union and Mexico. International Journal of Agricultural Resources, *Governance and Ecology* 12: 262-291.

Rey, F., Sinoir, N., Mazollier, C., Chable, V., 2013. Organic seeds and plant breeding: stakeholders' uses and expectations – French inputs on vegetables. *International Symposium on Organic Greenhouse Horticulture* 1041:133-139

Rey, F and Klaedtke, S. (2018). Common bunt case studies. Summary of "World café" with two subgroups and follow-up discussions. LIVESEED WP 2: Working group (unpublished).

Ruge-Wehling, B. and Jansen, G. 2014. Züchtungsmethodische Ansätze Zur Erhöhung Der

LIVESEED is funded by the European Union's Horizon 2020 under grant agreement No 727230 and by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00090.

Anbaubedeutung Der Gelben (Lupinus Luteus) Und Weißen Lupine (Lupinus Albus) Im Ökolandbau https://www.orgprints.org/28098/

Richter, T., 2012. Strukturen und Entwicklungen des Schweizer und internationalen Marktes für Saatgut am Beispiel ausgewählter Gemüsesorten. Bio Plus AG, Seon

Scholz, R.W. and Titje, O. (2002): Embedded case study research. Integrating Quantitative and Qualitative Knowledge. London: Sage Publications.

Sementi Biologiche http://scs.entecra.it/biologico-indice/biologic.html (Italian Organic Seed Database)

Simatupang, T. M., & Sridharan, R. (2004). Benchmarking supply chain collaboration: An empirical study. *Benchmarking,* 11(5): 484–503. https://doi.org/10.1108/14635770410557717

Solfanelli, F., Ozturk, E., Zanoli, R., Schäfer, F., 2019. Report on current production and use of organic seeds and synopsis of databases. LIVESEED Deliverable 1.2 (unpublished)

Storkey, J., Doring, T., Baddeley, J., Collins, R., Roderick, S., Jones, H. & Watson, C. (2015). Engineering a plant community to deliver multiple ecosystem services. *Ecological Applications*, 25: 1034-1043.

Thommen, A. (2007). Report on criteria list and evaluation guide for derogation regime. Deliverable 5.3 for the project EEC 2092/91 (ORGANIC) Revision, FIBL, Frick.

Verriere, P., Nuijten, E., Messmer, M. (2019). Organic plant breeding in a systems - based approach and integration of organic plant breeding in value chain partnerships. LIVESEED Report M3.5. https://www.liveseed.eu/wp-content/uploads/2019/10/LIVESEED_M3.5_WS-report_Integration-of-organic-plant-breeding-in-value-chain-partnerships-FIN.pdf

Wilhem, W. (2016). Perspective of a public-private partnership: An example of collaboration of a public research institute with a small and medium enterprise in Switzerland. Delley Seeds and Plants, Switzerland.

Willer, H., Lernoud, J., 2019. The World of Organic Agriculture. Statistis and Emerging Trends 2019. Research Institute of Organic Agriculture (FiBL), Frick, and IFOAM - Organics International, Bonn.

Winter, E (2019) Modelling framework agreed between partners. Unpublished Milestone Report 4.3 of LIVESEED, FIBL, Frick.

Wolfe, M. S., Baresel, J. P., Desclaux, D., Goldringer, I., Hoad, S., Kovacs, G., Loschenberger, F., Miedaner, T., Ostergard, H., Lammerts Van Bueren, E. T. (2008). Developments in breeding cereals for organic agriculture. *Euphytica*, 163(3): 323–346. https://doi.org/10.1007/s10681-008-9690-9

Yin, R. K. (2014): Case study research. design and methods. 5th Edition. Sage Publications: London.

LIVESEED is funded by the European Union's Horizon 2020 under grant agreement No 727230 and by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 17.00090.