STRATEGIC INNOVATION AND RESEARCH AGENDA FOR THE FRUIT AND VEGETABLE SECTOR

V2016

AREFLH EUVRIN EUFRIN FRESHFEL

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1 PREAMBLE

This document was produced by the joint task force for the fruit and vegetables sector composed by AREFLH (representing fruit, vegetable and horticulture regions in Europe), EUFRIN (representing fruit research institutes), EUVRIN (representing vegetables research institutes) and FRESHFEL (representing the fresh fruit and vegetables supply chain).

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Description of the organisations

AREFLH

AREFLH is a European Assembly of fruit, vegetable and horticulture regions (Assemblée des Régions Européennes Fruitière, Légumières et Horticoles). AREFLH is an assembly of 25 regions, representing more than 40 % of the fruit and vegetable European production and producer's main organizations. More information about AREFLH can be found via: http://areflh.org

EUFRIN

EUFRIN is an organization of university departments and research institutes that specialize in research, development, and extension on temperate fruit crops and which are based within countries of the European Union, Switzerland, and Eastern Europe. EUFRIN currently represents 22 countries. More information about EUFRIN can be found via their website: http://eufrin.org

EUVRIN

EUVRIN is an informal, voluntary organization of research institutes or research institutes departments that specialize in research, development, and extension on vegetable production, which are based within a number of countries of the European Union. It was set up and held its first meeting in Brussels on February 1, 2016. The current number of research institutes stands to 50 (Membership of and Participants in EUVRIN). More information about EUVRIN can be found on the website: http://euvrin.eu/

FRESHFEL EUROPE

Freshfel Europe is the European Fresh Produce Association, representing the interests of the fresh fruit and vegetables supply chain in Europe and beyond. Freshfel Europe currently has over 200 members, including companies, organizations and associations, ranging from producers to retail operators. More information can be found via: www.freshfel.org

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3 INTRODUCTION

The Strategic Innovation and Research Agenda (SIRA) is a document which identifies the main challenges facing the fruit and vegetable industry in Europe and proposes a list of priorities for public and private research investment in the coming period up to 2020 and beyond. The document has been elaborated in a joint effort between AREFLH[1], FRESHFEL[2], EUFRIN[3] and EUVRIN[4] and representing both the fruit and vegetable chain stakeholders and the fruit and vegetable innovation and research community. It is built on the 2015 Version of the SIRA, with a view to update priorities and expectations for the fruit and vegetables sector.

The European fruit and vegetable industry is a relevant sector of the EU agro-industry as, with less than 3% of total land use, it produces around 21% of the value of the total EU agricultural production. The combined fruit and vegetable sectors involve about 1.4 million farm holdings, with a total chain turnover of about 150 billion euro.

Fruit and vegetables represent an ideal food as they deliver unique nutritional value conferring protection from cardiovascular diseases, obesity and cancer, associated to taste, freshness and naturalness. Securing a steady supply of fruit, vegetables and their derived products for the EU consumer is a must vis-a-vis the food challenges that lie ahead in terms of projected demographic growth, climate change, sustainability and competition from the agrofood assortment. If Europe is to maintain a secure and safe supply of fruit and vegetables, it must invest in research leading to technological innovation to be funnelled into the chain.

The European fruit and vegetable sector is faced with global challenges including (i) need for higher competitiveness; (ii) sustainability and resilience (iii) climate change (iv) fruit and vegetables value (v) human health and well-being (vi) food safety and security. The horticultural sector faces the risk of being unable to adequately respond to these actual and upcoming challenges. Appropriate identification of innovation and research needs and priorities should lead to research programs that can efficiently tackle the challenges.

The EUROPE 2020 Strategy calls for a model of growth capable of addressing Europe's future societal, economic and environmental issues. Such growth must be smart (based on education, knowledge and innovation); sustainable (based on a resource efficient, greener and more competitive economy); inclusive (based on high employment and economic, social and territorial cohesion). The fruit and vegetable sector is in an excellent position to contribute to this growth via the adoption of innovation resulting in an improved and more competitive European fruit and vegetable supply chain. The SIRA addresses the innovation and research priorities, as identified by the stakeholders that can adequately respond to the identified challenges under the perspective of the EUROPE 2020 strategy.

[1] *AREFLH. Assembly of European regions producing fruits and vegetables. www.areflh.org*
[2] *FRESHFEL. European Fresh Produce Association. www.freshfel.org*
[3] *EUFRIN (European Fruit Research Institutes Network) is a voluntary network created to facilitate international cooperation among fruit researchers. www.eufrin.org*
[4] *EUVRIN (European Vegetable Research Institutes Network) is a voluntary network created to facilitate international cooperation among vegetable researchers. www.euvrin.eu*

4 CURRENT SITUATION OF THE FRUIT AND VEGETABLE INDUSTRY

4.1 INTRODUCTION

The fruit and vegetable sector is a fundamental sector in the EU as its production accounts for close to 21% of the value of the total EU's agricultural output, but only receives 3 to 5% of the CAP expenditure[5]. And for this the fruit and vegetable producers use ca. 3% of the EU's cultivated area. The total production value of fruit and vegetables is estimated to be more than 50 billion EUR with 1.4 million farm holdings. The industry estimates that the whole fruit and vegetables supply chain, including many jobs in the post-harvest production, but also wholesalers and distribution channels, has a turnover of more than 150 billion EUR with approximately up to 750,000 employees. As such, the fruit and vegetable sector is an important player when it comes down to labour and societal impact. More specifically, the processed fruit and vegetables (i.e. juice, pastes, etc.) has 10,200 enterprises employing 283,000 people generating a turnover of up to 53 billion EUR.

Fresh fruit and vegetables are high-value crops with a wide diversity in species grown in relatively small production areas. The majority of the crops are consumed or processed directly in the Member State (MS) where they are produced (67 % of production is marketed or processed on the 'local' MS market).

As such, the impact for the local societies is quite significant. The fruit and vegetable sector is providing many jobs, but also has great impact on the environment, sustainability of the landscape and is obviously contributing to human health. Farms often also contribute to important ecosystem services leading to a more sustainable use of the land. Fruit tree plantations in mountain areas, for example, provide stability, thereby contributing to prevention of soil erosion. Other important economic sectors, such as tourism, also benefit from fruit and vegetable production as this industry often makes environments more pleasurable, i.e. during bloom or near harvest.

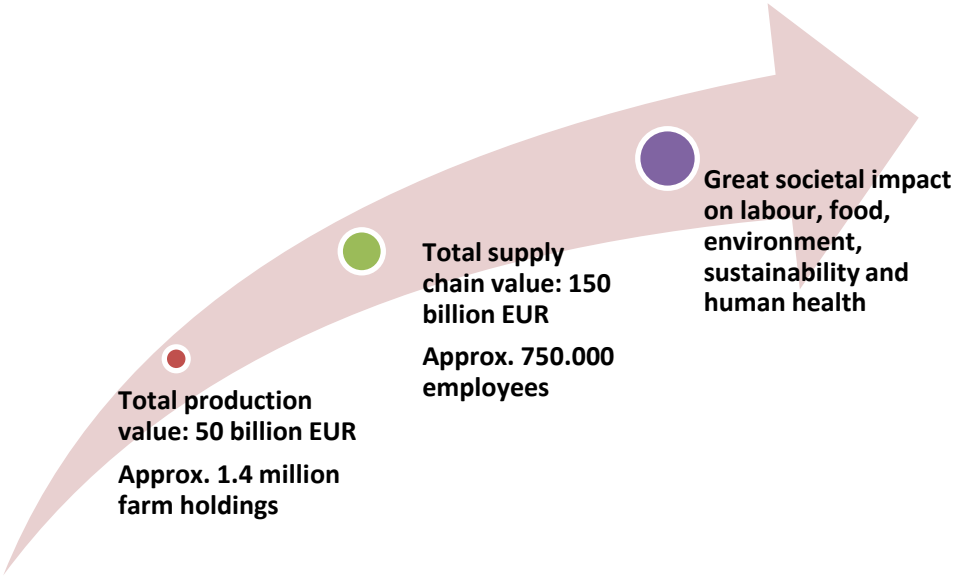


FIGURE 1 FRUIT AND VEGETABLE CHAIN VALUE

4.2 THE FRUIT AND VEGETABLE SECTOR

[5] *See information by the European Commission:* http://ec.europa.eu/agriculture/statistics/factsheets/pdf/eu_en.pdf

4.2.1 FRUIT AND VEGETABLE PRODUCTION IN EUROPE

The total EU fruit and vegetable production is ca. 120 million tons, of which ca. 70 million tons are used fresh, the rest being processed (such as grapes used for wine, tomatoes used for paste, oranges and apples for juice, etc.). Included in the 120 million tons are approximately 21 million tons of grapes grown for wine over ca. 3 million ha. Of the 70 million tons fresh production, fresh fruit production accounts for ca. 36 million tons and fresh vegetable production for ca. 34 million tons[6].

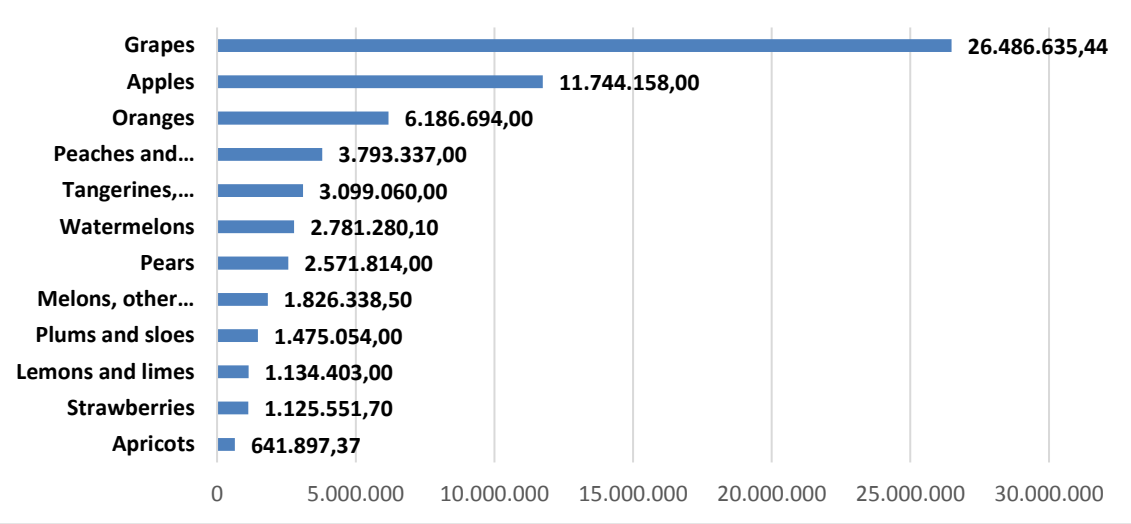


FIGURE 2 EU PRODUCTION FRUIT - 2013

The main fruits grown in the 28 Member States of the EU are grapes (*90% used for wine production), apples, oranges, peaches and nectarines, watermelons, pears, melons, plums, lemons & limes, strawberries and apricots (see Figure 2). The total production of these products is 67 million tons in 2013 over an area of ca. 6 million ha[7]. Looking at fresh production, these top twelve fruits are responsible for ca. 36 million tons across an area of ca. 6 million ha[8].

Looking at vegetable production, the top 12 vegetables produced in the EU are: tomatoes (of which a significant part is used for processing), salad beetroot and other roots, carrots and turnips, cabbages, cucumbers, lettuce and chicory, chillies and peppers, cauliflowers/broccoli, mushrooms, pumpkins, peas and beans (see Figure 3). Total production of these twelve products is 55 million tons over 2 million ha. Looking at fresh production only, these categories are responsible for 35 million tons across an area of ca. 2 million ha.

Fruit and vegetables are responsible for ca. 7.8 million ha (total) and 3 million ha (only fresh), which is quite limited compared to an area of 54 million ha for production of the main arable crops (wheat, barley, maize and rape).[9]

[6] *FAOSTAT data – EU production in quantity (t) for the year 2013*
[7] *As mentioned before, this is the total production, including fresh fruits and fruit going to be processed.*
[8] *FAOSTAT data – EU total production in quantity (t) and area harvested (Ha) for the year 2013 without HS factor Accessed via: Faostat http://faostat3.fao.org/download/Q/QC/E*
[9] *Idem, FAOSTAT*

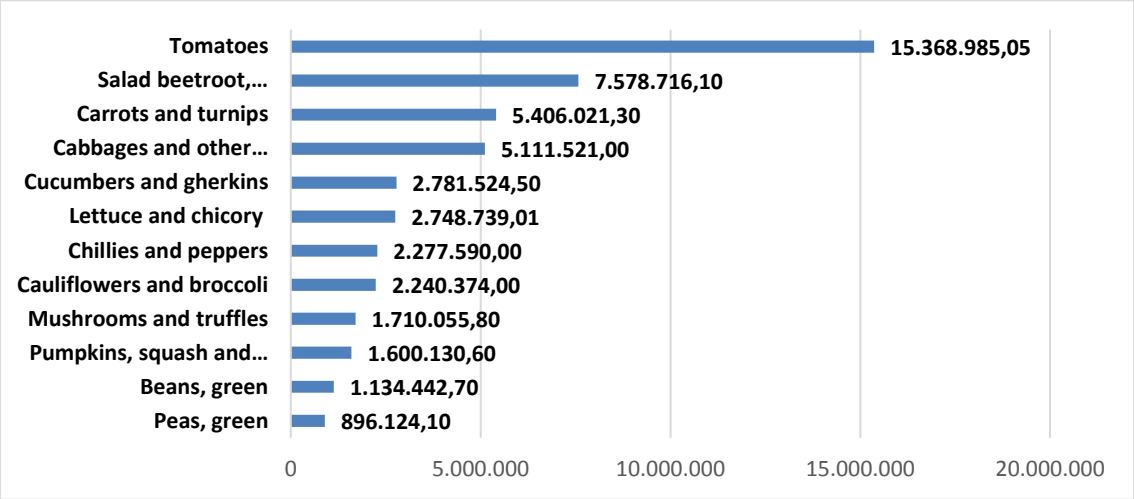


FIGURE 3 : EU PRODUCTION VEGETABLES – 2013

Looking at specific products, we can see that the bulk of the production is often concentrated in a few Member States. Italy and Spain have the largest fruit production, jointly producing 19 million tons out of the total 36 million tons of fresh fruit produced in 2013. Certain countries are also more specialised in their production, for example, some 57% of EU-28 apple production in 2013 was located in Poland, Italy and France, whilst 51% of the oranges were produced in Spain[10]. Strawberries on the other hand are more evenly divided amongst Member States. For vegetables similar trends can be witnessed, salad beetroots are produced largely by France and Italy, accounting for 43%. For cabbages, 58% are produced in Poland, Romania and Belgium. Of tomatoes, 69% were produced in Spain, Italy and Portugal. Of the fresh tomatoes 41% were produced in Spain and the Netherlands. Carrots are more evenly spread across the Member States. This also depends on growing conditions. For example, it is easier to grow carrots in any climate than oranges.

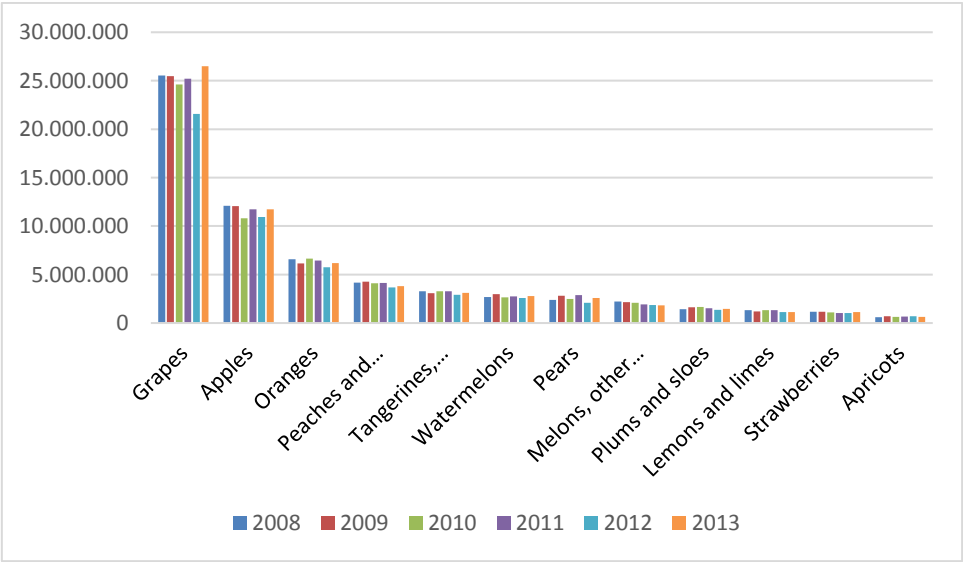


FIGURE 4 : FRUIT PRODUCTION EU 2008-2013

[10] *FAOSTAT data – EU production in quantity (t) for the year 2013*

Fruit production has been relatively stable over the last few years with mostly fluctuating results in production in the last five years from 2008 until 2013. Some fruits show only small declines in production over the five years. These top 12 fruit categories are responsible for ca. 94% of all fruit production in the EU. For the main fruit species there have been small declines in the areas of land under production from 2008 until 2014. The total land area under these 12 species has reduced ca. 4.5% since 2008. This has been partially countered by an increase in the level of intensification (i.e. production per unit area) over recent years through the use of modern production systems which include improved varieties, better planting systems and harvest season extension[11].

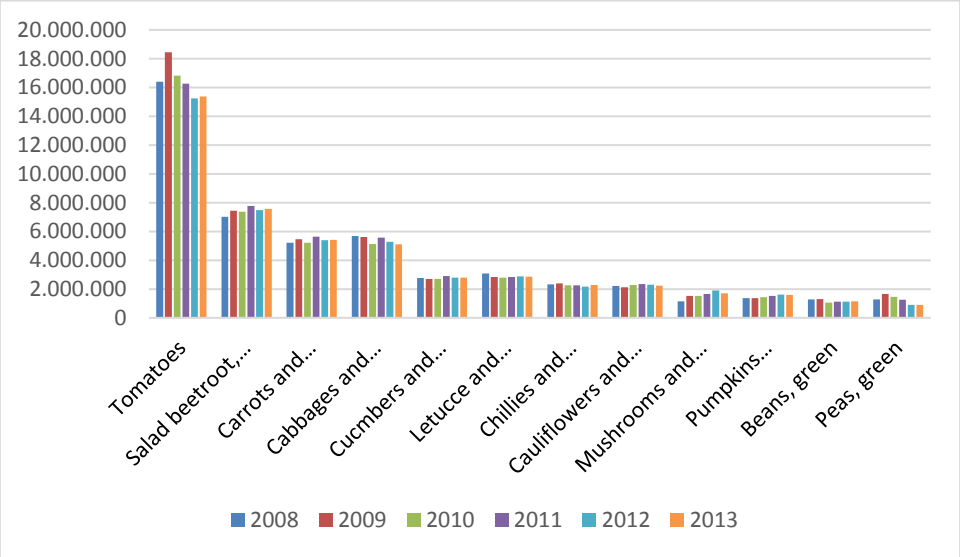


FIGURE 5 VEGETABLE PRODUCTION EU 2008-2013

Vegetable production also shows similar trends, although here the production shows some differences. Some products are on a steady increase (i.e. pumpkins as well as mushrooms), whereas others are on a steadier decline (lettuce and tomatoes). For the other products, they seem to be, either relatively stable, or more fluctuating between 2008 and 2013. In the total land used for this production, we can see that pumpkins and mushrooms both had increases in their land use (which could have also led to an increase in production). For the products that have been declining in recent years (lettuce and tomatoes) we also see a small decrease in land use. For the other products, the land use has been, either relatively stable, or more fluctuating, similar to the figures for production[12].

The average EU farm size (for all agricultural purposes, so not limited to fruit and vegetables) was 33 ha in 2012, but this varies heavily between different Member States. Certainly, countries such as Malta have considerably smaller farms, whereas other countries have considerably larger farm sizes. This depends on landscape, but also on local traditions[13]. In case of the fruit and vegetable sector, it comprises mainly of small farms and family farms.

4.2.2 Fruit and vegetable trade in Europe (intra EU and international)

4.2.2.1 Intra EU trade

[11] *FAOSTAT data – EU production in quantity (t) & in area harvested (Ha) for 2008-2013*
[12] *FAOSTAT data – EU production in quantity (t) & in area harvested (Ha) for 2008-2013*
[13] *DG Agriculture - EU Farm Economics Overview, based on 2012 FADN data. Accessed via: http://ec.europa.eu/agriculture/rica/pdf/EU_FEO_FADN_2012.pdf*

A large part of the production is consumed or processed locally, in the country where the produce has been grown. Obviously, certain products are not produced locally or are not fully consumed locally and as such there is a part that is being traded. Intra EU trade in fruit and vegetables comes mainly from the other Member States. Within the EU, around 30 million tons of EU fruit and vegetables are shipped among Member States out of a total production of about 70 million tons in 2015[14].

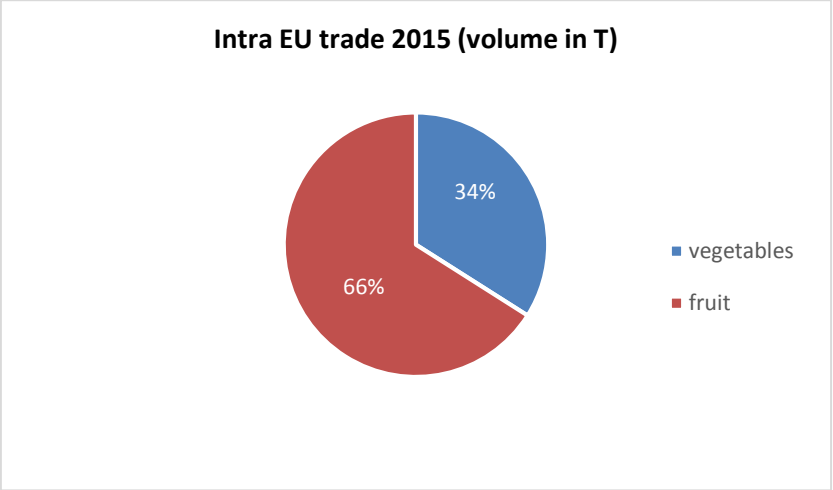


FIGURE 6 INTRA EU FRUIT AND VEGETABLE TRADE 2015

As can be seen from the table below, Spain, the Netherlands, Italy, Belgium and France are the main suppliers of fruit and vegetables to other Member States. The Netherlands and Belgium have a unique position, as they both are large trade-hubs and as such are importing and exporting goods that are not produced locally.

TABLE 1 MAIN EU SUPPLIERS TO OTHER MS - 2015

Main EU suppliers to other MS - 2015 (volume in t)			
Supplier	**Fruit**	**Vegetables**	**TOTAL**
Spain	6.812.306,30	4.484.963,50	11.297.269,80
Netherlands	2.306.600,40	2.712.877,90	5.019.478,30
Italy	2.332.008,00	752.079,20	3.084.087,20
Belgium	2.133.929,00	832.132,70	2.966.061,70
France	1.058.696,40	969.069,90	2.027.766,30
Germany	653.740,10	369.783,40	1.023.523,50
Poland	482.547,40	539.371,70	1.021.919,10
Greece	809.378,00	102.901,60	912.279,60
Portugal	482.547,40	287.010,40	621.036,40

[14] *Freshfel 2016 Freshfel Europe Activity Report 2016, p.12.*

Austria	204.699,00	138.974,70	343.673,70
Czech Republic	214.645,80	85.995,80	300.641,60
Hungary	144.358,10	90.390,10	234.748,20
UK	115.275,10	88.622,10	203.897,20
Slovenia	84.334,70	42.262,20	126.596,90
Other	355.848,00	269.005.50	624.853,50
TOTAL	**18.042.392,30**	**11.765.440,70**	**29.807.833,00**

Spain and Italy, but also France and Germany are large suppliers. Germany is the main recipient of fruit and vegetables (7 million T), followed by France (3.8 million T) and the UK (3 million T)[15].

As we can see, fruit is more often being shipped around Member States than vegetables. This also has to do with the production capacity for certain types of fruit and vegetables. The main commodities to move around in the EU are citrus fruit (from the southern countries to the rest of the EU), apples and pears (shipped more evenly), other vegetables, tomatoes and bananas (mainly being imported from third countries and then re-exported throughout the EU).

TABLE 2 VOLUMES FRUIT AND VEGETABLES - INTRA EU 28 MEMBER STATES 2015[16].

Commodity	**Export quantity (volumes in T)**
Citrus fruit	5.365.064
Apples & pears	3.290.936
Other vegetables	2.930.663
Bananas	2.680.417
Tomatoes	2.665.417
Stone fruit	1.734.249
Melons & papayas	1.707.858
Other fruit	1.389.215
Onions, shallots, garlic, leeks	1.370.820
Cabbages, cauliflowers...	1.157.845
Cucumbers & gherkins	1.155.296
Lettuce & chicory	1.135.785
Carrots, turnips, edible roots	1.073.410
Table grapes	1.022.771
Dates, figs, exotics	851.883
Leguminous vegetables	276.204
Total	**29.807.833**

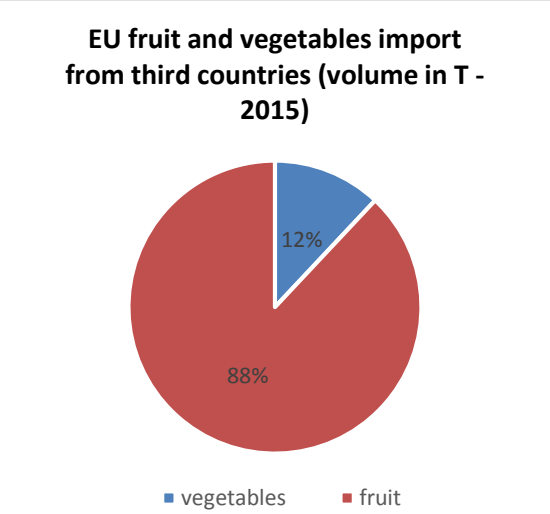
[15] *EUROSTAT data: EU intra trade importers in volume (T)*
[16] *EUROSTAT data: EU intra trade export in volume (T)*

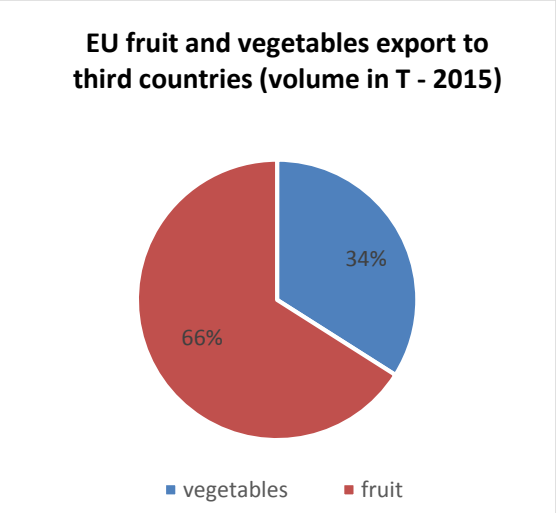
From the section above on intra EU trade, it should be clear that the fruit and vegetable sector is a great example of a functional EU internal market. The EU Member States are of great importance for one another when it comes down to the trade in fruit and vegetables.

Additionally, there are certain countries which are main trade-hubs, such as Belgium and the Netherlands, which are responsible for re-shipping products to other EU Member States. Even if they import products from outside the EU (which can be seen in the sub-chapter below), the EU internal market makes it possible that these products can be enjoyed throughout the European Union.

4.2.2.2 EXTRA EU TRADE

In 2015, the EU imported more than 13 million tons of fresh fruit and vegetables from third countries worth almost 14 billion EUR. Fruit is by far the largest category imported with 84% of all import from third countries. Bananas are the largest group of fruit products imported, followed by citrus fruits, exotics (i.e. pineapples, avocados, mangos, dates and figs) and apples.





EU imports from third countries in volume (t) - 2015		EU exports to third countries in volume (t) - 2015	
Costa Rica	1.744.321,30	Belarus	1.578.741,40
Ecuador	1.416.111,20	Switzerland	546.518,90
Colombia	1.384.665,50	Norway	332.456,50
South Africa	1.188.614,60	Brazil	323.099,70
Morocco	1.031.535,50	Egypt	263.998,90
Turkey	772.420,30	Algeria	177.886,20
Brazil	559.763,50	Senegal	174.924,40
Chile	500.605,20	Ukraine	158.865,70
Peru	471.350,20	United Arab Emirates	151.866,70
Dominican Republic	356.577,10	Russian Federation	148.707,80
Total top 10	**9.425.964**	**Total top 10**	**3.857.066**
Others	3.915.216	Others	2.004.663
Total imports	**13.341.179**	**Total exports**	**5.861.729,00**

The main vegetables imported are tomatoes, as well as other vegetables, not classified in specific categories[17].

As can be seen from the table, the EU imports the majority of its fruit and vegetables from Costa Rica, Ecuador, Colombia, South Africa, Morocco, Turkey, Brazil, Chile, Peru and the Dominican Republic. They represent over 70% of all imports from third countries coming into the EU. The top four countries (Costa Rica, Ecuador, South Africa and Colombia) account for 43% of all imports.

Exports amount to 5.8 million tons worth ca. 4.4 billion EUR. With export to third countries there are more vegetables being exported, but still fruit remain dominant. The percentages here are around 66% and 34% for fruits and vegetables exported. The main exported fruits are apples followed by citrus (mainly oranges, mandarins and tangerines), pears, peaches and nectarines and kiwifruit. For vegetables, the main exported products are onions and shallots, as well as tomatoes and other, non-classified vegetables[18].

4.2.3 FRUIT AND VEGETABLE CONSUMPTION IN EUROPE

The daily net[19] fruit and vegetable consumption in the EU is 341.81 gr. per capita. This represents an increase of 5,6% compared with 2012, and a decrease of 1,9% compared with the average of the previous five years (2008-2012). In certain Member States the situation is quite reasonable, where the consumption equals to the WHO's recommendation of 400 grams per day, but in other Member States the situation is not as positive.

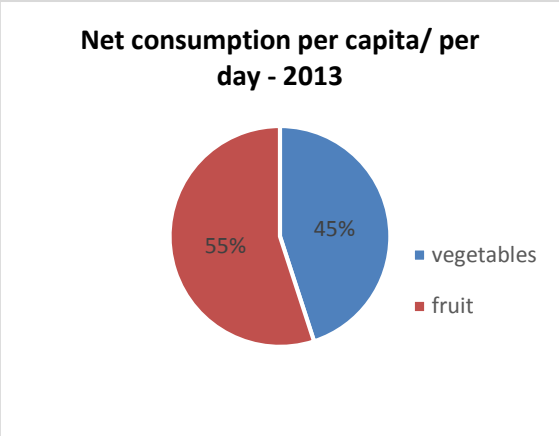


FIGURE 7 NET CONSUMPTION PER CAPITA/PER DAY 2013

[17] *EUROSTAT data – EU import from third countries by volume (t) and value (EUR) 2009-2015*
[18] *EUROSTAT data - EU export to third countries by volume (t) and value (EUR) 2009-2015*
[19] *Net consumption means that food waste has been taken into account (everywhere where net consumption is mentioned, a moderate percentage of 20% has been deducted from the gross amount for food waste).*

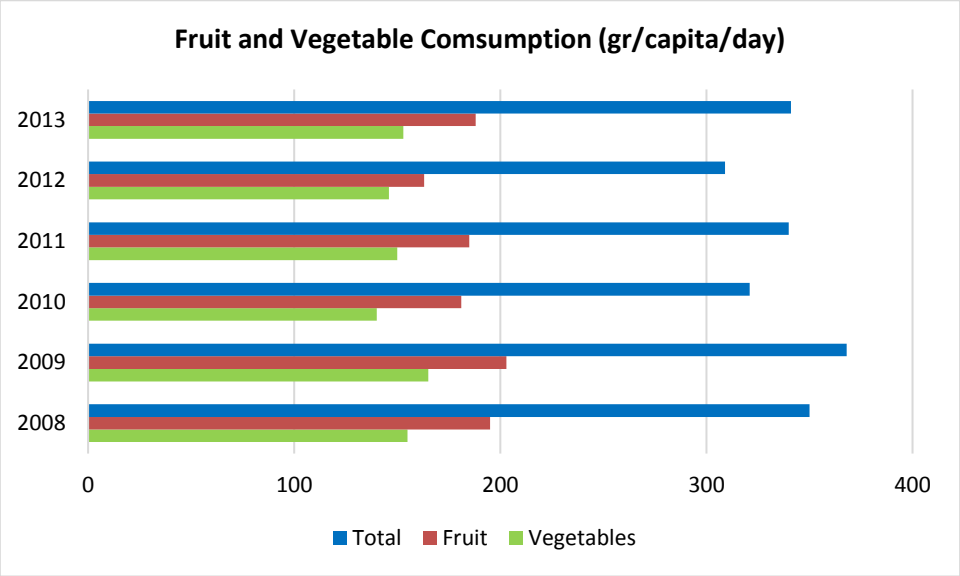


FIGURE 8 FRUIT & VEGETABLE CONSUMPTION (GR/CAPITA/DAY)

The breakdown between fruit and vegetables shows a net daily fruit consumption of 188.60 gram per capita in 2013. This represents an increase of 10,1% compared with 2012, and a decrease of 1,5% compared with the average of the previous five years (2008-2012). For vegetables, the net consumption in 2013 was 153.22 gram per capita per day. Vegetable consumption increased by 0,5% compared with 2012 and decreased by 2,3% compared with the average of the previous five years. This is a concern set against a background of rising obesity, but also shows the potential for increased consumption[20].

The data reported here highlight the alarming trends of a stagnating or even declining consumption of fresh products. To properly address this shortcoming, Europe needs to mobilize its resources of the fruit and vegetable chain to improve the promotion and support efforts of the European fruit and vegetable industry. Particularly considering the rising EU trend of obesity and obesity-related illnesses and diseases, fruit and vegetable consumption should be stimulated as much as possible.

4.3 THE FRUIT AND VEGETABLE CHAIN

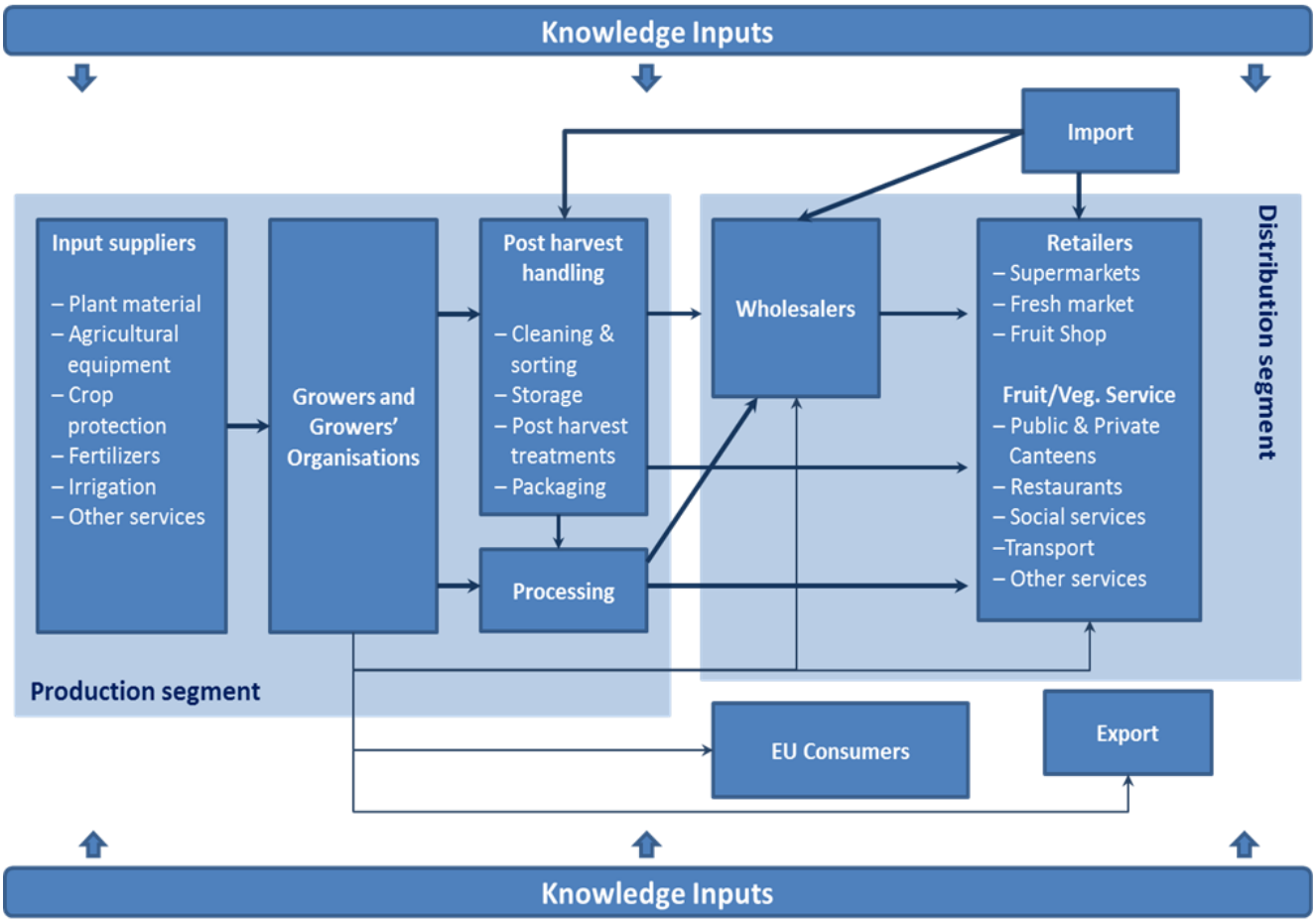
The fruit and vegetable chain has a complex structure (see figure below) involving e.g. input suppliers, growers & grower organisations, post-harvest handlers, logistic operators, distributors, retailers, food services and consumers. The production segment includes input suppliers, growers and post-harvest. Input suppliers provide basic materials and services. Growers can be grouped in growers' organizations or cooperatives, in which case they often directly carry out post-harvest handling and/or processing. Marketing desks, wholesalers, markets and retailers represent the distribution segment of the chain delivering fresh and/or processed fruit to the final consumers. Other participants include importers/exporters, brokers, logistics service providers (transport) and waste managers. At every step of the chain, there is an on-going demand for highly specific and advanced knowledge, to foster and support the necessary continuous improvements of the entire chain[21].

[20] *Freshfel 2015 – Freshfel fruit and vegetable production, trade, supply & consumption monitor in the EU 2013*
[21] *Martinez-Palou A and Rohner-Thielen E 2008 Fruit and Vegetables: fresh and healthy on European tables. Eurostat statistics in focus 60/2008. Eurostat, European Commission, Brussels.*

Retailers can vary from farm shops, markets, grocers and supermarkets and can be regarded as specialist and non-specialist. The latter due to their large sizes may hold considerable power when negotiating prices with suppliers and wholesalers. The type of retailer varies from one country to another, but the multiple retailers (i.e. supermarkets) take a large share of the fresh produce market in many countries. For example, in the UK, supermarkets account for about 80% of fresh produce sales. Very high quality is required by supermarkets which results in high technical demands and an increasing interest in technology that maintains quality along the whole supply chain. Fruit and vegetables are also unmistakably present in the highly diversified food services. Food services includes public and private canteens (i.e. schools, hospitals, jails), catering, food in transport (i.e. food on trains and planes), restaurants and restaurant chains, social and health outlets, the army, and others.

The number of specialist fruit and vegetable retailer enterprises is ca. 76.500 employing 170,000 people with a generated turnover of 12.5 billion EUR. The average size of specialist fruit and vegetable retailers is small, ranging from one person in Finland to six persons in the Netherlands[22].

FIGURE 9 - THE FRUIT & VEGETABLE SUPPLY CHAIN[23].



[22] *Martinez-Palou A and Rohner-Thielen E (2008), cited earlier in footnotes*
[23] *Based on Martinez-Palou A and Rohner-Thielen (2008)*

5 EUROPEAN FRUIT AND VEGETABLE INDUSTRY IN THE CONTEXT OF THE GLOBAL CHALLENGES

The main growth drivers in the fruit and vegetable sector are convenience and portability, health and safety, new products and category innovation.EU consumers are continuously demanding products of high quality, which makes fruit and vegetables more suitable for new and improved lifestyles. In addition, the modern fruit and vegetable industry needs to retain economic competitiveness, achieve full sustainability and respond to climate change. To reach these objectives, the development of innovative technologies integrating diverse disciplines will be required to maintain the prominent role of fruit and vegetable growing within the EU social and economic scene.

5.1 INWARD CHALLENGES

5.1.1 COMPETITIVENESS

Current trends in the horticultural sector are frequently a dichotomy with opportunities arising in both directions e.g. globalization vs. regionalisation, convergence vs. divergence and consolidation vs. fragmentation.

There is a trend towards consolidation of production and supply with a parallel increasing emphasis on global/regional partnering and commercial alliances. This trend reflects the increasing power of retail brands to meet buying power and logistical demands. The convergence includes the food, health, agricultural, industrial and biotech sectors. This brings with it a need for a multidisciplinary, flexible and integrated approach to science and technology development. The trend is also evident in research providers/funding systems as they move towards collaborative programmes and virtual networks.

Many of the trends are driven by the increasing competitiveness of the business environment. This competitiveness is particularly strong where there are fewer market entry barriers, where markets are saturated or demand is flat, and where low cost structure regions/countries compete. Global trade barriers are lowered or overcome by merging key players within the trading blocks, resulting in increasing international global competition.

There is a steady increase in global fruit and vegetable production in parallel with population growth worldwide. The key challenge will be how to compete in the long run, as without sufficient growth in demand cannibalisation results across all fruit markets and causes strong downward pressure on prices. In order to stay competitive despite falling prices, production costs may have to be reduced through efficiency gains.

Fruit and vegetable producers and suppliers therefore need to differentiate themselves from their competitors by demonstrating better cost structures, higher quality/consistency of product, ability to meet demand, efficient production systems, flexibility to incorporate new technologies trends, continuous and faster stream of new products, rapid technology change and adoption, and decreasing product life cycles. Additionally, retailers wish for suppliers who are actively integrated into the entire production-to-consumer cycle.

5.1.2 SUSTAINABILITY AND RESILIENCE

Sustainability involves economic, environmental and social aspects. Economic criteria used in modern market-oriented agriculture, such as the yield or gross margin are no longer sufficient for an evaluation of horticultural/agricultural practices, which should include an assessment of their environmental impact (e.g. carbon footprint, life cycle assessment, energy use, biodiversity, etc.). Separation of economic and environmental sustainability is undesirable, as economic activity inevitably affects the environment and those impacts are currently paid for by society at large. These environmental impacts are now raising

consumer concerns over product standards. As a result, the sector is confronted with a proliferation of private standards, which have an impact on production systems. Rising interest in good farm practices (e.g. GlobalG.A.P.) is a response to this concern for process standards. Both short and long-term environmental impacts of existing and future horticultural practices need to be quantified, yet it is recognized that not all stakeholders along the food chain share the same interests and values. Europe is well placed to take advantage of sustainability issues due to climate diversity, product and process innovation, and has a reputation for quality and differentiated products. The rising demand for limited energy supply associated with production and transport leads to increased production costs, which will favour the local producer/supplier over the global trader. The fruit and vegetable sector is also well placed to support the forefront role of Europe in leading worldwide efforts towards increased stewardship of renewable resources. Fruit and vegetable production already consumes far less water than other food production sectors, but it has great potential for further reductions of these inputs without compromising quality and quantity of production. At the same time, "smart" production systems like decision support systems for pest management or intelligent sprayers and plant based fertilizer applications, will become increasingly widespread, leading to further reduction in inputs. In turn, these will drive down the use of fossil energy sources, thus reducing the carbon footprint of the sector. Collectively, these changes will contribute to the creation of a resilient system, which represents the ultimate goal in terms of sustainability.

5.1.3 CLIMATE CHANGE

Constraints for horticultural production under natural environments will worsen when the predicted climate changes will occur, leading to multiple stresses in form of higher average daily temperature and/or less precipitation throughout the growing season. Higher ambient temperature will lead to increased plant organ respiration and reduced plant water use efficiency with detrimental consequences on biomass production (yield) and product quality (fresh and processed produce). An increase in temperatures will also produce an advance in the phenological stages of fruit trees, leading for example to earlier flowering dates, but can also lead to increased risks of spring frosts. Another consequence could be an insufficient satisfaction of chilling requirements for flowering, which would lead to an erratic and delayed flowering and, at the end, a decrease of productivity. Higher evapotranspiration and reduced precipitation will result in a strongly negative climatic water balance which has to be compensated through irrigation systems to ensure sustainable horticultural field production. However, sufficient water availability is not likely expected throughout the summer months due to price rises of arable crops, which make especially irrigation of grain and maize more and more profitable, and the possibility to overcome logistical and energetic challenges in an economically justifiable manner. Consequently, it is expected that total water consumption and the competition for water will increase in agricultural and horticultural production systems. A drastic decline of water consumption is therefore needed in the future; a demand which can only be met through crop specific and optimal mitigation and adaptation strategies such as irrigation and other production processes. On the other hand, because of climate change, it is also expected that more occurrences of 'extreme' weather conditions will take place, such as unpredictable events leading to e.g. flooding, where of course a different water management should be maintained. The consequences for the land and soil can also be quite severe, so these elements must be thought of when coming up with innovations in the fruit and vegetable production sector (and agriculture in general) in the future.

5.2 OUTWARD CHALLENGES

5.2.1 VALUE OF FRUIT AND VEGETABLES

Fruit and vegetable quality research is strongly aligned with many of the strategic growth trends currently identified in the global food and agribusiness sector. Scientists, partners along the food chain and industry end-users need to be aware of these trends as they represent the best opportunity for the European market. The key trends are as follows:

- Significant opportunities in the special food markets, including those foods that are 'differentiated' through health (including hypoallergenic), functional, organic or indulgent aspects.
- Consumer expectations of 'positive eating' experiences.
- Increasing interest in healthier diets.
- Increasing middle and high income consumers (including those in low income countries) who are seeking an 'added value' component to their food purchases.
- A complex food chain that has moved from a production push to a consumer pull, thus demanding increased focus on consumer needs.

Two pathways are already existing which connect plant-based research providers and end-users through partnerships:

- The conventional route to quality (primarily achieved through research partnerships with fruit industry and growers) has a history of innovation and technology uptake (new cultivars, Integrated Fruit Production, organic growing, marker-assisted breeding). The key indicator of contributions to relevant end-user outcomes is the high level of industry investment, adoption and further development of new technologies, innovations and products.
- The genetic route to quality follows the plant biotechnology value chain. This involves forming new in-house and external partnerships for germplasm evaluation, construction of databases and gene sequences, identifying candidate genes that control key plant responses, and testing the performance of such candidate genes in trees and in model systems. This is a more 'in-depth' knowledge-driven path that requires a strongly integrated, multi-disciplinary science approach, including conventional methods, to ensure a 'quantum leap' for the fruit and vegetable industry and related plant-based industries.

5.2.2 Human Health and Well-being

The nutritional value of specialty fruit and vegetable crops is in their rich sources of vitamins, minerals, fibre, acids, sugars and secondary metabolites in biologically functional forms. The key significance of diet and nutrition of fruit and vegetables is in the well documented effects on prevention of obesity, diabetes and cardiovascular diseases by mechanisms that are at this time only partially understood. Horticultural products are known to be important for health and wellbeing of humans by regulating digestion processes, supplying slow-release sugar, reducing blood pressure, affecting uptake and metabolism of fats, and possibly by delaying the aging processes.

Secondary plant metabolites are significant non-caloric components of plant-based food products, and many of these can affect health. Those bioactive compounds (e.g. polyphenols such as anthocyanins, flavones, flavonols, flavanols and phenolic carboxylic acid as well as carotenoids and other terpenoids, stilbenes, complex cell-wall components and many others) have pre-biotic, anti-inflammatory and antioxidant potentials which are often connected with prevention of metabolic diseases, aging-related disorders, allergies, rheumatism, cardiovascular complications and possibly certain cancers. Metabolites with pharmacological effects are for example lutein (i.e. improving vision in the elderly), polyphenols and cell-wall components in apple (e.g. reduction of cholesterol), xanthohumol in hops (e.g. induction of apoptosis in prostate epithelial cells) and the stilbene resveratrol in grapes and berries (e.g. cardio-protective and anti-inflammatory properties). Growth conditions such as solar UV-radiation slow ripening and water availability can strongly affect the biosynthesis of polyphenols and other secondary metabolites in plants which in turn affects their bio-functional properties.

An increased fruit and vegetable consumption at the population level is a real opportunity to improve health and wellbeing of humans. The demand for health-giving foods can be characterised as such:

- change from “corrective” medicine to “preventive” medicine and self-care through diets, nutritional eating and exercise
- increasing demand of functional ingredients/food products and dietary supplements
- individuals taking more health responsibility, with health foods considered the most important instrument

5.2.3 Food Safety and Security

The World Bank (WB 2008)[24] estimates that 1.0 billion people (15% of the world’s population) are affected by extreme poverty. In particular and in consequence of the world food crisis, the number of undernourished people living in developing countries reached 907 million, and 923 million worldwide, in 2007[25]. The large number of undernourished people, however, marks only the peak of the global nutrition problem. A great many more suffer from food insecurity in general – a situation characterized by an inadequate access, both in physical and economic terms, to sufficient, safe, and nutritious food for an active and healthy life[26]. Food insecurity is not only related to animal-based products and arable crops, but also to horticultural produce with health-giving properties. Despite a range of European policies and intervention programs, poverty and food insecurity, which are closely related and may even reinforce each other, remain also critical issues within the European societies. Aside from undernourishment in severe cases, food insecurity often leads to a less evident form of malnutrition than the simple lack of sufficient food quantities, namely to micronutrient malnutrition (‘hidden hunger’) that is mainly caused by a lack of food of adequate dietary quality. Rough estimates suggest that about one-third of the world’s population – mostly children and women – are deficient in at least one essential vitamin or trace mineral.

Labelling is required for nutritional/compositional information and ISO certification/tracking of food production for safety reasons is increasing. There is a shift from what the product is, to what the product can do. These developments require the use of new technologies (e.g. “omics”) to monitor and document foods, both for regulatory reasons and for product safety reasons. The development of safe processes and methods of detection of unsafe processes is becoming increasingly important, as is the ability to demonstrate their use in the development of a new product.

The production of safe products largely rests on innovation that combines advanced technologies with environment respecting approaches. Intelligent sprayers, such as the ISAFRUIT developed CASA-Sprayer[27], illustrate how state-of-the-art engineering can be complemented with biological knowledge of pests and pest cycles. This together can achieve a control of parasites with up to 50% reduction in chemicals applied. To the same end, the adoption of natural control methods (e.g. microbial competitors, hot water treatments) can help control diseases while significantly increasing crop safety. Management of irrigation based on real-time assessment of environmental conditions and plant requirements (which are related to crop growth stage) can lead to significant water savings without compromising the quality. Similar benefits can be reaped by the adoption of computer models that combine soil analysis to fruit and vegetable growth requirements, leading to reduced fertilizer inputs.

5.2.4 Social Economy

Fruit and vegetable growing is a long-term endeavour, as orchards go through an early unproductive phase lasting a few years, before they begin the positive part of their economic cycle, which often lasts more than a decade. This requires careful turn-over planning, to renew aging orchards and/or adopt new

[24] *The World Bank Annual Report 2008*
[25] *The State of Food Insecurity in the World 2008. FAO.*
[26] *World Food Summit, FAO, 1996*
[27] *for more information see the two links below:*
http://www.jhortscib.com/isafruit/isa_pp107_112.pdf
http://www.youtube.com/watch?v=FFD0znlba50&noredirect=1

improved varieties as they become available, and the market may require. This turn-over is ingrained within fruit growing and mandates stability of the agricultural enterprise, placing fruit and vegetable growing at risk whenever economic and/or social scenarios are created that favour abandoning this activity. The risks to society associated to this loss of technical, cultural, economic and social heritage are beyond description in their consequences.

The coexistence of orchards and natural landscapes is the background of many environmentally gifted regions of Europe. The continuous adoption of advanced technologies to reduce the environmental footprint of fruit and vegetable growing, goes hand in hand with time-honoured growing practices that are recognized and appreciated as part of the cultural heritage and tradition of these growing regions. This adds no small measure of economic impact to those regions where the beautiful landscapes are a factor contributing to well-being and to boost the tourist industry. Furthermore, fruit and vegetable growing provides protection to the environment from losses due to meteorological and climatic factors, contributing to reducing the effects of extreme environmental hazards, such as erosion, flooding, etc.

Because of its high intensity of cultivation, fruit and vegetable growing is an important provider of employment to skilled labour, as pruning, picking, and in general performing growing practices require a high degree of specialization. In addition to this direct effect, fruit and vegetable growing provide further economic opportunities related to the production, handling, trade and consumption.

6 WEAKNESSES AND GAPS IN FRUIT AND VEGETABLES INDUSTRY

6.1 CURRENT STATUS AND RISKS

The importance of primary production in our food supply is often underestimated, despite its essential role in delivering fresh fruit and vegetables, and underpinning the supply of ingredients for food manufacturing companies. Many governments have endorsed the consumption of fresh fruit and vegetables as a critical part of a balanced diet to ensure health and wellbeing of consumers. However, currently agricultural production systems have been underfunded and there are questions to be raised as to whether current systems are equipped and prepared for highly dynamic changes as expected under increased environmental regulations, extreme climatic conditions and limitation of input resources. To date, the production of primary products has focused on incremental gains, including better targeting of fertilizers and water use, prediction systems to reduce chemical use, and evaluation of new cultivars. According to the European Commission the transformation to sustainable societies in a changing environment is a priority. Therefore, we need a paradigm shift in how food is produced in order to meet future requirements and targets. The reduction of using resources such as water, and the implementation of crop protection approaches that minimize the use of pesticides and the inputs, and thus the residues on the fruit, are but two examples of such a paradigm shift.

6.2 FRUIT AND VEGETABLES ATTRIBUTES AND CONSUMER EXPECTATIONS

Fruit and vegetable production in Europe is facing many challenges in the market place due to increased consumer expectations for quality, taste and uniformity, combined with significant changes in lifestyle and food consumption patterns. The greatest driver for the consumption of fruit and vegetable is taste, therefore focus on development and delivery of high taste cultivars, combined with technologies and approaches to manipulate, sustain and deliver products to the consumer with high taste attributes is essential. In addition, consumer awareness of the multiple health-related benefits of fruit consumption is not sufficient to boost fruit consumption. This lack of knowledge is, at least in part, due to the limited efforts to promote them within the fruit and vegetables chain (the proportion of TV commercials promoting fruit and vegetables as opposed to snacks is quite revealing). Instead, many consumers, despite checks by regulatory authorities attesting the contrary, are concerned about the safety of fruit and vegetables which are perceived as “residue carriers”, unless they are produced in “old, traditional ways”. In the eye of the general public fruit and vegetables growing could have become reminiscent of idyllic scenes, recalling past traditions and bucolic settings, as always represented by the media. This in turn can make consumers sceptic about the benefits deriving from the uptake of technological innovation in the fruit and vegetables chain, which often leads to the rejection of significant improvements in the production systems, while accepting outdated cultural practices that have lost their effectiveness due to their economic, or their environmental impact.

Consumers are also interested in increased convenience of products, as there has been a significant increasing trend in the consumption of prepared fruit and vegetable snacks and fruit based beverages. Fresh fruit and vegetables are struggling to compete with the convenience and homogeneity of other less healthy manufactured snack products such as potato crisps and chocolate. Manufactured snack products tend to have a relatively short product development lifecycle and a short product life. In contrast, breeding and developing a fruit cultivar for commercialization is a long-term commitment and requires significant investment. To conceptualize the size of this weakness we will compare ‘apples’ to ‘a manufactured chocolate bar’. The chocolate is highly uniform, the taste experience is consistent, and the product is readily available independent of climate and natural extremes. If a production change is made during manufacturing of the chocolate bar, this change can be implemented on a global scale and it can create an instant impact in the position of the end product in the market place and the competitiveness

of that product. Contrary, if a new technology is introduced into the production systems for apples, this technology will need to be evaluated on many levels, such as apple variety, growing region, climatic variability and various national regulatory restrictions within the many, diverse fruit growing regions where apple is grown. Due to the existing environmental and climatic variability it can take several years to collect the data to justify a production change and the likelihood that this advancement in technology will be implemented on a global scale is very low because the global fruit and vegetable industry is fragmented and competitive.

One of the most significant weaknesses in fruit and vegetable production is the biological variation that exists between individual fruit and vegetables, partly due to the differences between growing areas, which is of no help in overcoming the overall challenge of the industry to meet consumer expectations. Product variation leads to a variable taste experience and consequently a reduced consumer satisfaction. Technologies, approaches and advancement in overcoming or managing product variability are essential to underpin the competitiveness and the trustworthiness of the fruit and vegetables sector. Ensuring consistent quality will secure a premium, increase the likelihood for repeat purchase, and ensure a competitive position for fruit and vegetables products against less healthy manufactured food goods.

There is also a significant need for scientific evidence documenting the health benefits of fruit and vegetables and their consumption. Developments of advanced and increased efficiencies and technologies at different stages in the production chain are needed. An improved understanding of the genetic traits that influence the development of novel and superior cultivars is essential. Consumers also have an increased awareness and wish for locally produced fruit and vegetables and their derivatives. This focus on 'regionality' is underpinned by a need to deliver a reduced carbon and water footprint and to increase the sustainability of production practices. Consumers also demand that the fruit and vegetables industry is accountable for safety and traceability with respect to chemical use, chemical residues, and environmental impacts of the productions systems. Therefore, there is an increasing need for new cultivar development with improved disease tolerance that can be grown under low chemical input systems or organic production systems, and for cultivars with increased efficiencies with respect to water and nutrient use. It is essential that these cultivars also deliver superior taste and quality attributes in addition to an economic yield.

6.3 FRUIT AND VEGETABLES PRODUCTION AND INDUSTRY CHALLENGES

Fruit and vegetables producers in Europe are facing reduced economic returns, due to having a reduced control in the market place. Consolidation within the fruit and vegetables industry has led to a small number of larger storage and packing facilities that tend to focus on a narrow range of products, varieties etc. This has led to fewer products and less diversity in the market. Consolidation of supermarkets has followed a similar trend resulting in supermarkets having an increased decision making power in the market place with respect to pricing and product availability to consumers. Consequently, fruit and vegetables producers have focused on increasing productivity and being able to differentiate their products through delivering novelty into the market place in an attempt to secure a premium. Supermarkets currently hold a large share in the market for fruit and vegetable sales. A challenge is the competitiveness within the chain, where low returns to fruit and vegetables producers negatively impact the ability to implement competitive changes because of a limited capacity to invest in new technologies. Regulatory changes are needed within the structure of the food chain, to ensure a future role for fruit and vegetables producers in the food chain. Regulatory changes should encourage investment within the fruit and vegetables industry, which should increase the return on investment in research and development. This will secure implementation of research outcomes which will increase the competitiveness and efficiency of the industry.

Biological variation arising during the production phase also creates significant challenges to the distribution segment of the chain. Variation during production leads to compromises in harvest, packaging and storage decisions. Decisions on when to harvest, what to harvest into, how to grade and store the fruit and vegetables is all compromised based on variability across a normal distribution. This poses a very serious hurdle to the possibility of creating fruit and vegetables brands, which might offer a competitive advantage to growers in terms of obtaining better prices. The experience of "fruit clubs" until today is probably positive for the growers, but it has the obvious limitations inherent to the concept of "controlled scarcity of supply", i.e. the concept only works if just a handful of growers is producing the crop. In contrast, the manufactured goods are highly uniform and can be optimally packaged, handled and transported as all the products are the same. Consequently, throughout the fruit and vegetables production chain 30% of all fruit and vegetables is wasted. Given future societal challenges on the imbalance between the volume of food produced and population, a focus on how to minimize wastage is critical. The EU Integrated Project ISAFRUIT has for example carried out ground breaking work on developing a Decision Support System capable of integrating information from the pre- and post-harvest sectors of the chain, with the aim of providing storage managers/wholesalers estimates of the storing potential of each fruit, so that they can be managed differently, according to their specific quality traits, and the potential for storing without loss of eating quality. Such systems are still in their infancy and more work is needed before they can be fully implemented.

Nitrogen loss is a major problem for open field vegetable production and for greenhouse production in soil, which is common in southern Europe. Most vegetable crops have high requirements for nitrogen fertilizers in order to maintain high and profitable levels of production and quality. However, vegetable production is commonly associated with low nitrogen efficiency. Some common characteristics of vegetable production create challenges for efficient nitrogen management. Often vegetable crops have a requirement for vigorous growth at harvest to ensure high quality products, and shallow root systems, and some are harvested during the late autumn which can leave appreciable residual nitrogen in root zone from where it can be leached by winter rainfall. Nitrogen loss to water bodies from vegetable production represents a major threat to the water environment causing nitrate contamination of subterranean water and eutrophication of surface water bodies which challenges the goals of the EU Water Frame Directive of minimal contamination of subterranean water and reaching good ecological status of surface water bodies.

Fruit and vegetables production and its associated production challenges pose many research questions. The chain is complex and each researcher has expertise in a fraction of the total chain. Therefore, there is a need for science based solutions focused on the development and advancement of primary production itself. Increasing environmental regulations have led to fewer solutions available to producers and they are reliant on research solutions to be able to deliver a quality product. Alternative approaches to spraying and use of energy are needed to deliver sustainable tools for producers. Reduced access to pesticides and a focus on decreasing chemicals use and residues means that new knowledge and exchange of knowledge between research and industry is essential to sustain the horticulture industry into the future. Due to the complexity of the fruit and vegetables production system and the diverse research skills and expertise needed, only a few countries, if any, can cover all research topics within the fruit and vegetables food chain. Small countries or minor crops have a lack of research funding to cover all aspects of the chain; this is a limitation as the ability to develop some of these crops into significant industries is therefore also very limited. Consequently, collaboration between countries is an essential tool to exchange knowledge and ensure access to scientific expertise that any single institute, region or country does not have. The establishment of a platform for the integration of fruit and vegetables research in Europe provides a significant opportunity to strengthen fruit and vegetables research, fruit and vegetables production and to exploit nationally based knowledge resources and to secure dissemination of new research solutions at an international level.

6.4 SCIENTIFIC CHALLENGES

All European countries are conducting research on fruit and vegetables. This research includes a wide range of disciplines. Relevant disciplines are, amongst other, market research, consumer behaviour, plant protection, tree and fruit physiology, agronomy, genetics and breeding of new cultivars using a suite of technologies. Technical attributes of plants are also a major focus within fruit research including physiology, production methods, quality, safety, security, nutrition, bioactivity effects, health of fruit and vegetables consumption, pests and diseases, effects of pesticides, sustainable production methods, organic production methods, and production technologies including automation, ICT, robotics and sensors. Research is often focused on the production of a crop within a region. In general, research is carried out in partnership with growers or grower industries to ensure knowledge exchange and capability development to enable industries to be nationally and internationally competitive. Breeding of new cultivars or evaluation of new cultivars is usually carried out at a national level. A special weakness within the scientific approach to fruit and vegetables research is that often, as stated above, this research is mostly relevant within defined regions, and this has led to it being carried out predominantly at a national level, based on national regulations for use of chemicals and climatic and environmental differences. The other side of this coin is that, even though the projects carried out have been scientifically efficient and reached a real and significant scientific community, often this research suffers from lack of critical mass in order to be able to generate important results that may impact in a positive way the value chain. Therefore, strong collaborative research initiatives which cross national borders are critical to accelerate knowledge exchange between countries and to lift the overall success and to secure the future of the European fruit and vegetables industry.

7 IDENTIFICATION OF INNOVATION AND RESEARCH NEEDS TO ADDRESS THE GLOBAL CHALLENGES

7.1 PARTICULARITIES OF THE CHAIN

Global challenges affect the entire chain. They are not related to specific sectors, rather they overlap across the chain. However, the strength of the effect or how to face those challenges have specific traits that result in different assessments regarding what the needs are in each section of the chain.

Competitiveness is a must for all actors in the chain. After all, fruit and vegetable production is an economic activity and without a minimum threshold of economic competitiveness, business in this sector in a short or long term would disappear as such. However, the pressure on profitability seems to be much higher in the production phase than further up in the chain. Often, overproduction or political crises result in a price crisis that puts pressure on growers and causes the activation of the measures provided in the common market organization. Similarly, sustainability issues are much more pronounced in the production link. Pesticide usage or resource optimization (soil, water, fertilizer, energy …) are also challenges more tied to the production phase than to either the distribution or storage and handling. On the other hand, challenges of consumer knowledge and added value seem to be more related to links further up the chain or throughout the chain.

According to this, the needs for innovation and research have been identified and separated by different parts of the chain: Input Suppliers and Production, Handling and Storage, Distribution and Consumers.

7.2 RESEARCH NEEDS FOR INPUT SUPPLIERS AND PRODUCTION

The EU fruit and vegetable production sector is challenged with producing a diverse supply of inexpensive fruit and vegetables essential to the health and well-being of the EU population. In doing so, they must meet (a) consumers demands for varied, high quality and nutritious fresh produce, with negligible amounts of plant protection products or contaminants and (b) citizens' increasing demands for food production with minimal negative environmental impacts. The latter must be done within an environmental framework of limited or reduced supplies of fundamental resources e.g. water, and societal pressure to reduce external inputs of nutrients and energy. These multiple and related challenges will be most effectively solved with solutions based on scientific knowledge. The overall challenge must be to improve and enhance current production systems, using sound science-based solutions. Approximately 95% of fruit and vegetables are produced with modern, intensive and increasingly sustainable production systems, as opposed to alternative production systems (e.g. organic agriculture). The most effective contribution to further sustainable intensification and advancement of modern fruit and vegetable production will come from sound science-based developments that specifically address environmental, social and economic (i.e. sustainability) issues of current production systems.

The research needs for primary production cover the following areas: Genetic Resources and their Utilization; Sustainable Plant Protection; Efficient Use of Primary Resources; Enabling Technologies: Robotics and Precision Horticulture; and Greenhouse Production. While field production systems are still the most important way of producing fruits and vegetables, greenhouse production systems are increasingly important and becoming mainstream in certain crops. They are technologically more intensive in the different research areas and generate a higher production per ha. Both production systems have common research needs but at the same time technology or development level can be specific. Their needs and perspectives are discussed below. While each of the research areas can contribute to tackle at least some of the priority issues set out in the "Strategic approach to EU agricultural

research and innovation" (*e.g.* those dealing with Resource management and Healthier plants)[28], various interactions between them can be envisaged leading to the development of interdisciplinary/transdisciplinary approaches (Figure 10). A systems-based approach can be gradually implemented integrating multiple areas and assessing the performance of horticultural systems across space, time and the potential economic, environmental and social benefits.

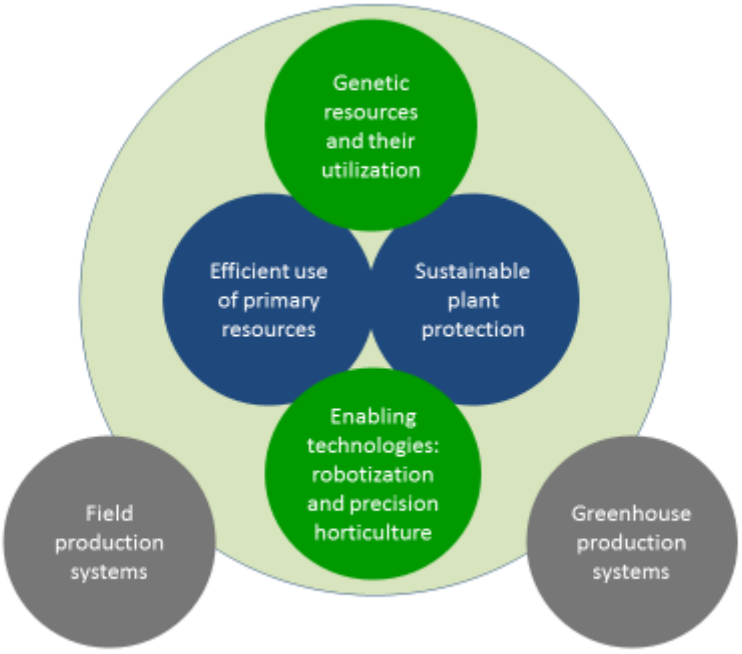


Figure 10 Research areas in fruit and vegetable sector are interconnected. Field production systems cover the largest areas and still are the basis of the sector. Greenhouse production systems, however, are expanding continuously and are technologically more developed. Sustainable intensification research is needed for both.

Most research areas need continuous activity to generate fully effective results that can be implemented in practice. Genetic resources need research provisions over a longer term because the breeding and the evaluation of new genetic material is a time-consuming activity, especially for perennial crops. Fruit and vegetables cover a broad range of crops in a broad range of plant families. They are all susceptible to different pests and diseases and are grown in a wide range of cropping systems (field or protected, soil or soilless, etc.) and (changing) climatic conditions. One IPM solution for all does not exist: IPM programmes are specific and have to be tailor-made for each crop, each cropping system and climatic region. Additionally, existing IPM programmes are continuously challenged by new pest and diseases introduced into the EU through the international trade of fruit and vegetables. New IPM solutions have to be developed and integrated in the existing systems. Developing IPM-programmes (compulsory in the EU) that emphasize the replacement of chemical control is a major research topic that needs continuous EU-support. The same can be said for water and nutrient use, which must be tailored to the specific characteristics of individual crops, cropping systems and climatic conditions. To meet the goals of the EU Water and Nitrates Directives continuous research and extension efforts are required.

[28] *https://ec.europa.eu/programmes/horizon2020/en/news/final-paper-strategic-approach-eu-agricultural-research-and-innovation*

7.2.1 GENETIC RESOURCES AND THEIR UTILIZATION

Utilization of appropriate plant material is key for successful and sustainable fruit and vegetable production. Unfortunately for the main fruit and vegetables species, varieties use a narrow genetic base and thus they are not taking full advantage of unexploited genetic resources where might lay the potential solution to increased environmental, economic and social sustainability.

Climate changes are a threat to the diversity of cultivated crops, contributing to genetic erosion. In addition, climate changes are already challenging current European horticultural systems with new pests and diseases as well as environmental constraints linked to water availability and quality, salinity and high temperatures. Biotic and abiotic stresses have an impact on productivity and quality, making the breeding of varieties with improved adaptability, resilience and tolerance/resistance a must. To counteract climate changes, the introduction of novel genetic resources (*e.g.* new varieties or species) can be also envisaged, requiring the acquisition of new genomic information and the development of new breeding activities. Robotic automation is not yet totally applicable in many horticultural crops, particularly for harvesting and packing, with impacts on crop management costs. To cope with this aspect, varieties with characteristics adapted to the automated chain (size of fruit, concentration of ripeness, etc.) should be developed. Moreover, cultivars capable of maintaining yield and quality standards in low input conditions (less pesticides, fertilizers) and with reduced energy demands (*e.g.* adapted to sub-optimal growing conditions in cold greenhouses) could help reduce greenhouse gas emissions and environmental pollution, allowing further expansion of cultivation areas. Finally, considering the high diversification of markets and consumers' needs, many quality targets have to be taken in account for fruit and vegetable products, prompting the development of varieties with highly specific characteristics.

Several constraints might affect the process of development of novel varieties in fruit and vegetable species. The reproduction system, the scarce information on the genetic basis of important agronomic traits, the low efficiency of phenotypic selection and, especially in fruit crops, the long juvenile period and long growth cycle make the introgression of useful genetic variation and the development of new varieties difficult and/or very slow. Innovative breeding methodologies could speed-up and improve the development process for releasing improved varieties able to meet the progress of agricultural technologies and the demand of low inputs. In previous EU research Work Programmes, there have been significant investments and progress in this area. However, there is still an urgent need for continued public support to ensure a flow of research results towards the industry, especially to face new challenges of increased sustainability and climate change.

In this area, the identified research topics are:

1. New genetic resources for species with a narrow genetic base
2. New or traditional genetic resources for sub-optimal conditions
3. New genetic resources for specific needs of the value chain
4. New breeding techniques
5. New genomic information and tools

Breeding new high quality fruit and vegetable varieties meeting consumers' preferences and segmented market demands

Specific challenge:

Continuous innovation in the plant breeding sector requires the development of new varieties able to face major challenges such as population growth, climate changes and overexploitation of natural resources. On the other hand, the evolution of globalized markets and of consumers' demands influence various food trends e.g. health, convenience, pleasure, social. Consumption of fruits and vegetables with better nutritional value helps promote health and prevent chronic disease such as obesity, micronutrient deficiency, cancer and cardiovascular diseases. Traditional and new markets require high quality products, able to meet the changing of food habits, based on product diversification, busy lifestyle and mass production practices, and the different needs of people with varying age, culture, specific diseases or proneness to suffer from specific diseases, etc. Hence, the fruit and vegetable sector has to be very dynamic and continually adapt to the highly variable consumers' needs and environments (geographical areas, cultural practices, business segments), providing a wide range of adapted varieties. With the aim to satisfy consumers, industry and all other stakeholders' needs, it is imperative to produce differentiated vegetables with good sanitary, organoleptic and nutritional quality to supply all population categories, and promote, at the same time, low-input, sustainable and environment-friendly agriculture.

Scope:

Based on cutting-edge genomic knowledge and multidisciplinary approaches, proposals must aim to develop novel fruit and vegetable varieties addressed to different consumers' categories, and showing high and regular yield, resilience to major biotic and abiotic stresses, better sensory characteristics and improved appearance, flavour, texture and nutritional value. Main pillars should be covered by the following aspects:
i) Identification of market segments and relative needs, in order to define the strategies to adopt. Differentiation includes both small growers interested to local markets and specialist growers producing for fresh market or processing. The resulting varieties should be differentiated on the basis of cycle duration, harvesting automation, processing suitability, etc.
ii) Exploitation of the large variability present in landraces and heirloom varieties in breeding programs aimed to enhance the amount of health related compounds in fruit and vegetables (e.g. polyphenols, vitamins, lycopene, carotenoids, glucosinolates, fibers) and develop novel functional foods
iii) Development of "superior taste" food through the investigation of the genetic and metabolic bases of aroma, flavour, and fruit texture, and the link with consumer sensory preferences
iv) Exploitation of secondary metabolites in protective functions related to biotic and abiotic stress conditions and for the development of novel products, such as pharmaceuticals, cosmetics, cosmeceuticals and new agro-chemicals.
Under the concept of 'multi-actor approach', various stakeholders, including producers, consumers, seed-bank curators, breeders, and researchers, should be involved in the choice of proper objectives, traits and genetic materials, in order to facilitate a faster development and acquisition of improved genotypes.

Expected impact:

Projects are expected to:
- Provide diverse and high quality products in terms of taste and nutritional value to the EU consumers
- Improve EU economies through the expansion or creation of new products and markets
- Promote the use of landraces and heirloom varieties for breeding for quality
- Develop novel varieties able to cover the needs of different market segments.

Developing new breeding techniques to promote the valorisation and a better use of horticultural genetic resources

Specific challenge:

The vegetable and fruit sectors represent a major component of European agriculture and the derived economy. Research on such crops, grown in highly diversified environments and whose products are consumed either fresh or processed, is important considering also their high value for nutrition and low impact on the environment. Genetic resources underpin adaptation of horticultural systems to fast and continuous changes in environments and consumers' requirements. A large number of genetic resources, including crop wild relatives and local (old) varieties, are conserved in *ex situ* and *in situ* collections. In addition, local varieties of fruit and vegetable crops are still grown and propagated in various European regions, based on their adaptation to specific environments and presence of valuable traits. Several projects worldwide, some of them funded by the EU, aim to characterize such collections exploiting new genomics and phenomics tools, allowing the accumulation of a large amount of data. Nevertheless, notwithstanding such abundance of genetic resources and related data, the overall level of biodiversity in horticulture and the extent of its use in breeding are reducing, with threats to economic, social and environmental sustainability of horticultural systems.

Scope:

New breeding techniques must be developed and adapted to a wider number of crops and varieties in order to increase the use of genetic resources in present and future horticulture systems. Submitted proposals should consider the development of appropriate methods to efficiently and precisely correct specific defects of local varieties (e.g. susceptibility to new pathogens), which are otherwise good for other aspects, such as taste and consumer acceptance. Furthermore, proposals should also develop methods to facilitate the exploitation of genetic variability possessed by wild relatives of crops, but not easily accessible through conventional breeding methods, due to hybridization barriers, linkage drag and/or reproductive features not amenable to repeated cycles of crossing and selection. Indeed, due to the transfer of unwanted characteristics and/or breaking of valuable genetic assortments, long backcross cycles are usually required to return to agronomically valued types. Under the concept of a 'multi-actor approach', various stakeholders, including producers, consumers, seed-bank curators, breeders, and researchers, should be involved in the choice of proper objectives, traits and genetic materials, in order to facilitate a faster development and acquisition of improved genotypes.

Expected impact:

Projects on this topic are expected to:
- secure EU agricultural systems with a wide and reliable genetic base
- promote the use of (improved) local fruit and vegetable genetic resources by increasing their ability to withstand new challenges and their economic sustainability
- increase the accessibility to genetic resources stored in seed banks and to related genomic information
- promote the activities of European small and medium sized seed companies and tree nurseries, facilitating their access to genetic resources and their use in breeding programs
- promote private-public partnerships favouring seamless transfer between research results, pre-breeding and varietal innovation
- provide farmers with new tailor-made varieties with improved agronomic characteristics and nutritionally enhanced food product traits able to satisfy the demands of novel and segmented markets
- preserve European consumers' and producers' preference towards local and traditional food products.

OMICS technologies for key processes in high quality fruit production

Specific challenge:

Key processes in fruit production like regulation of crop load, growth control or fruit maturity, are still monitored using traditional methods that are often unrelated to the underlying genetic and physiological bases that control these processes. In addition, whilst in other knowledge areas, genomics, transcriptomics, proteomics and metabolomics technologies are being used increasingly as diagnostic tools, in fruit production very little development has taken place to make full use of these new technologies.

Scope:

The project will make use of knowledge gained from different technologies which may include, among others, genomics, transcriptomics, metabolomics and proteomics to develop and implement tools to deliver constant and predictable fruit quality and levels of health promoting compounds to European consumers. These new technologies will be able to detect the basic processes initiating quality changes in the product. Key processes in the fruit production chain such as cultivar choice, regulation of fruit crop load, growth control, fruit maturity monitoring at harvest and prediction of physiological disorders in storage and further along the supply chain will be considered. The proposal will integrate the whole fruit production chain from the tree to the consumer.

Expected impact:

This project is expected to give the EU fruit sector a competitive edge for the stable production in European countries of high quality fruit containing health promoting compounds by:
- providing diagnostic tools to monitor and control crop load, growth and maturity
- providing diagnostic tools to major physiological disorders.

7.2.2 SUSTAINABLE PLANT PROTECTION

Public concern about the effects of pesticide utilization on human health and the environment has led to continuous changes in techniques of pest and disease management. This has resulted in the development of Integrated Pest Management. Albeit significant improvements, there is a need for alternative methods to chemical pest control that can further reduce pesticide utilization and guarantee fruit and vegetables that are practically free from pesticide residues. In this respect new improvements in spraying techniques that take into account the position in the field relative to sensitive targets (wells, buildings, social areas), tree size, climatic conditions at the time of application and the spatial distribution of pests and diseases are needed to ensure a lower utilization of pesticides and less impact on the environment. In addition, strategies to combat new pests and diseases introduced into Europe (e.g. *Tuta absoluta*, *Drosophila suzukii*) and old resilient pests (fire blight, etc.) are in high demand, as well as strategies to manage pests and diseases that can hinder access for fruit and vegetables to non EU markets. According to Directive 2009/128/EC of the European Parliament and of the Council 'establishing a framework for Community action to achieve the sustainable use of pesticides', Member States should promote low pesticide-input pest management, in particular, 'Integrated Pest Management' and establish the necessary conditions and measures for its implementation.

The challenge for a more sustainable management of plant diseases is that it must be addressed with a multidisciplinary approach through the integration of different types of knowledge with the potential to have an impact on fruit and vegetable crop protection. A synergistic integration of IPM innovative methods with strategies developed in other scientific fields, must be pursued to gain reduced use of chemicals, increased efficiency, improvement of food quality and increased potential for the development

of biologically-based vegetable productive systems, such as organic agriculture. For example, studies on genetic resources may be relevant for disease control to find pathogen's resistance/tolerance or materials suitable for grafting. Omics able to describe plant-pathogen-environment interactions may be crucial to design new control methods or to lead to very targeted management strategies. In parallel, implementation of digital solutions coming from engineering and bioinformatics, including sensing, imaging, disease modelling, etc., could be helpful to develop tools to assist disease management and well-calibrated decision support systems to enable precision application of crop protection tools. On the other hand, strategies to combat new quarantine pests and diseases introduced in Europe and old resilient pests (fire blight, etc.) are in high demand, as well as strategies to manage pests and diseases that can hinder access for fruit and vegetables to non EU markets.

The EU has supported a number of focus groups on important areas of agricultural production launched under the European Innovation Partnership (EIP-AGRI) 'Agricultural Productivity and Sustainability'. The Focus Group on "Integrated Pest Management (IPM) - Focus on Brassica species" and "IPM practices for soil-borne diseases suppression in vegetables and arable crops" formulated recommendations for further research that should be implemented in new projects.

The following innovation and research topics have been identified:

1. Innovative IPM practices with lower environmental impact, lower chemical residues and enhanced sustainability
2. Improvements in soil suppressiveness for reduced pesticide input
3. New (quarantine) pests and diseases
4. Old and disrupting pests and diseases
5. European pests review and mitigation measures for market access
6. Smart spraying techniques

Improving pest and disease control and reducing use of pesticides: a challenge for sustainable fruit and vegetable production

Specific challenge:

Fruit and vegetable production in the EU is challenged by decreasing consumption, a loss of competitiveness due to high labour costs in relation to other regions in the world and the political goal to significantly reduce pesticide use. In addition, consumers and the markets that supply them are demanding a large reduction, ideally the elimination, of pesticide residues on fruit and vegetables. This challenge is particularly strategic for such products consumed (partially) fresh.
Although Integrated Production has already given a good contribution in reducing the level of residues, alternative systems to pesticide use are recommended and expected by both EU regulation and markets to improve quality of agricultural production and environmental safety. Indeed, according to Directive 2009/128/EC, Member States should promote low pesticide-input pest management, in particular, 'Integrated Pest Management' and establish the necessary conditions and measures for its implementation. In the previous decades, pesticide use has been reduced substantially using decision support systems, the intensive use of beneficials and more recently but still emerging, the introduction of biological plant protection products. However, consumers and markets are demanding produce with virtually no presence of pesticide residues, far below the maximum residue levels.

To attain this goal, major research efforts are needed to design productive, sustainable fruit and vegetable production systems, which rely less on pesticide use. Fruit and vegetable crops and their pests, pathogens and weeds are extremely diverse and for most crops the range of effective alternative control methods is currently very limited. Specific solutions for leafy vegetables and for fruits and fruity vegetables have to be developed. Recently, aphids are developing resistance to parasitoids and every

year new diseases and pests appear and spread throughout Europe, putting the actual (biological) control systems in danger. Relationships in tritrophic systems are complex, sometimes counterproductive and the complex food web is not fully understood.
Upstream, research should focus on sustainable genetic resistance to diseases and the development of new molecular biology tools. These proposals do not preclude continuing trials with a view to requesting approval for active substances for minor uses, which are increasing in the vegetable sector.

Scope:

Proposals should provide the EU fruit and vegetable sector with new tools, strategies and techniques for pest and disease management to reduce the use of pesticides and residue concentrations in final products including:

- Reliable, cost-effective and simple monitoring systems and decision support systems based on thorough knowledge of the complex food web and trophic interactions in the crops to improve efficacy of treatments – this is relevant for both pesticidal and non-pesticidal (e.g. biological) methods of control.
- Control strategies for new and increasing pests and diseases.
- Control strategies with fewer side effects on beneficials are needed.
- Alternative ways of applying insecticides. Seed treatments, drenching and precision spraying should be explored further.
- Understanding how biopesticides should be applied to achieve maximum effect.
- More efforts to breed for pest and disease resistance.
- Alternative control strategies such as those using pheromones and cultural and physical methods of control.
- More research on plant defence elicitors.
- More research to understand if it is feasible to implement functional biodiversity and at what scale.

Proposals should study the complete fruit and vegetable chain, from the producer, packer, to the retailer and finally the consumer, involving different stakeholders to evaluate the technical, economic, environmental and social performance of IPM systems. To this end, proposals should fall under the concept of 'multi-actor approach', from the producer to the researcher, thus allowing for the adequate involvement of all stakeholders in the proposed activities. This will facilitate the rapid uptake of the knowledge generated within the project by the farmers

Expected impact:

1) Pest and disease management solutions that enable the EU fruit and vegetable sector to find alternative solutions through environmentally friendly systems in order to reduce the use of pesticides, to minimize the occurrence of residues on fruits and vegetables, and to preserve the environment, whilst maintaining sustainable production of high quality fruit and vegetables for the consumer.
2) Production and post-harvest handling systems to ensure competitiveness of European growers and societal acceptance
3) An increase in European fruit and vegetable consumption.

Technologies to improve disease suppressiveness of soil against soil-borne diseases

Specific challenge:

Disease suppressiveness of soil represents a natural barrier against plant pathogen development and maintains disease incidence and severity at very low levels. However, the intensive exploitation of soils (i.e. monoculture, increasing number of crop cycles per year, mechanical soil tillage, loss of organic matter, continuous use of mineral fertilizers and chemicals, etc.) leads to the progressive depletion of the soil ecosystem function. In this respect, intensive vegetable cropping systems, both in the open field and in greenhouses or polytunnels, are particularly exposed to high risks of soil-borne diseases.

Diseased soils are characterized by increased amounts of pathogen inoculum, reduced diversity and antagonistic functioning in microbial communities, and hypogeal environments which become conducive to soil-borne plant diseases. Deleterious effects on cropping systems are recrudescence of old diseases and/or emergence of new soil borne pathogens, generally poor growth, decline in both crop yield and quality, and reduced efficiency of the inputs. Rigorous disease management is necessary for vegetable production in these soils and requires a growing number of external control tools, including chemical fumigation of soil and use of fungicides. Limitations on the use of chemical pesticides due to EU regulatory restrictions and due to market concerns about food safety, make crop production more expensive and potentially unsustainable. Research is necessary to correctly identify the plant pathogens causing soil sickness. Based on that knowledge, alternative soil management methods should be designed. Promising technologies need to be developed so that EU vegetable growers can implement them to aid the recovery of soil health and fertility, increasing soil suppressiveness and improving soil productivity. This challenge will allow the sector to reduce its dependency on fumigation, synthetic fungicides, promote food security and incentivise vegetable consumption. Research should be focused on elucidating the cause of soil sickness, the development of technologies to improve suppressiveness of soil, based on the application of organic amendments and derivatives, biological control and biotechnological tools, and physical and mechanical practices. Specific studies should focus on measurement of changes in the soil microbiome and chemical and physical characteristics due to new management strategies, linked with an increase in disease suppression.

Scope:

Research should provide new strategies and tools and/or technologies, to i) identify the causes of soil sickness, ii) develop innovative solutions for soil sickness management iii) restore/increase the levels of natural soil disease suppressiveness in intensive vegetable productive systems, iv) reduce the need for chemical fumigants and fungicides and v) enhance sustainable vegetable growing systems in the EU. This should promote food security, crop yield and quality, and vegetable consumption. The adoption of rational, innovative and sustainable cultivation technologies is required to enhance the soil's ability to sustain plant growth and health by triggering beneficial functioning of the natural microbiome.

Expected impact:

1) Correct identification of the causes of soil sickness and soil borne diseases and innovative methods to manage them, prevention of soil sickness and diseases by restoring/increasing natural suppressiveness, thereby improving production efficiency in EU vegetable growing systems;
2) Preservation of soil fertility, soil health and key ecosystem services;
3) Reduction of the need for chemical fumigants and fungicides with benefits for the quality and safety of EU vegetables.

7.2.3 Efficient Use of Primary Resources

Horticultural production systems are intensive and require growers to make many management choices that impact on the profitability of the operation. Growers constantly strive to adopt improved growing techniques to boost efficiency and performance. Decision Support Systems, based on intensive monitoring of key parameters (growth performance, environment, soil humidity and fertility levels, etc.), will increasingly assist growers in adopting innovative management strategies, aimed at identifying the most critical production factors and optimizing their application so to improve yields and product quality while reducing the carbon, nitrogen and water footprints.

The most relevant improvements in the near future are foreseen in the area of accurate management of irrigation, in order to reduce water amounts used in fruit and vegetable production. In addition,

optimization of nutrient management in fruit and vegetable production is needed to avoid pollution of the water environment. There is major potential in the development of technological solutions such as decision support and sensor systems to monitor and manage fertilizer application. In addition, management strategies should be exploited to improve the use efficiency and recycling of nutrients at field and farm level. This can be done through the development of crop rotations, intercropping, catch crops and waste management.

Other aspects, however, including innovative approaches to the management of the orchard light environment via photoselective materials, such as coloured nets or films, will also contribute to improve efficiency and save primary resources such as water and energy.

Optimizing nitrogen use efficiency and securing yields in vegetable production

Specific challenge:

Modern vegetable production requires high inputs of nitrogen; most is applied as mineral fertiliser. Because of the lack of adequate tools and management procedures, excessive nitrogen application is common which in turn often results in nitrogen contamination of water bodies. This jeopardizes meeting the requirements of the EU Water Framework Directive. Simply imposing ad-hoc restrictions on nitrogen use will reduce yields and growers incomes by creating nitrogen limitations. There is a requirement for the development of management tools and approaches that enable optimal nitrogen management for the diverse vegetable crops and cropping environments of the EU.

Scope:

Proposals should provide growers, throughout the EU, with (i) tools and approaches to precisely assess the amount and timing of fertilization, and (ii) management strategies to increase nitrogen use efficiency and recycling of nitrogen at field and farm level. The overall aim is to reduce nitrogen losses to water bodies, appreciably reduce the amounts of N fertiliser applied, ensure high yields, and optimise product quality in line with EU consumers' expectations. Solutions can be high technology (e.g. optical sensors, decision support systems) or agronomic approaches, or judicious combinations of both. Solutions should be practical, user-friendly, and both labour and cost efficient. Proposals should fall under the concept of "multi-actor approach", from the producer to the researcher, thus allowing for the adequate involvement of all stakeholders in the proposed activities. This will facilitate the rapid uptake of the cross-knowledge generated within the project.

Expected impact:

1) Ensure that EU society has a plentiful supply of high quality vegetable products grown with appreciably reduced nitrogen losses to the environment, thereby meeting consumers' expectations of sustainable production of vegetables.
2) Provide EU vegetable growers with practical, easy-to-use management tools and management strategies that will enable commercially viable and environmental-friendly vegetable production
3) Ensure that the EU vegetable production is associated with sustainable land use by meeting environmental demands of the Water Framework Directive

Irrigation management for diverse species to optimise water use efficiency, production and product quality.

Specific challenge:

Fruit and vegetable production greatly benefit from water application. However, these crops involve an extremely diverse group of plants in terms of above and below ground physiology and morphology, climatic requirements, length of growing season and production systems amongst other considerations. Despite its usefulness, irrigation in many regions is threatened by limited water supplies, which are often subject to intense competition by other societal groups. Commonly, irrigation management is based on experience with little use of science-based practices for determining irrigation amounts and timing. Inefficient irrigation practices are often associated with over-exploitation and degradation of the quality of scarce water resources. Consequently, there is a pressing and continually-increasing requirement to optimise water use efficiency in fruit and vegetable production.

Scope:

Proposals should provide fruit and vegetable growers with information, tools and techniques to (i) accurately determine the amounts and timing of irrigation, and (ii) manage salinity to maintain soil quality. The information, tools and techniques provided should be useful for diverse production systems and for growers with different levels of knowledge with respect to modern technologies such as ICT.
They should result in reduced water use, less drainage of water and nutrients to water bodies, ensure high yields, and optimise product quality in line with EU consumers' expectations. Salinity management should be incorporated to manage soil quality and optimise product quality.
Solutions may be high technology (e.g. decision support systems, soil sensors and plant sensors), or agronomic approaches, or combinations of different approaches. Solutions should be practical, user-friendly, and both labour and cost efficient, and suitable for use by as many growers as possible. Proposals should fall under the concept of "multi-actor approach", from the producer to the researcher, thus allowing for the adequate involvement of all stakeholders in the proposed activities. This will facilitate the rapid uptake of the knowledge generated within the project.

Expected impact:

1) Provide EU fruit and vegetable growers with practical, easy-to-use management tools and strategies for irrigation that will enable commercially viable and environmentally-friendly fruit and vegetable production
2) Ensure that the EU fruit and vegetable production is associated with sustainable land use by meeting the various requirements of the Water Framework Directive
3) Ensure that EU society has a plentiful supply of high quality fruit and vegetable products produced with irrigation practices that optimise water use efficiency and minimise adverse effects on water bodies.

Fertigation management to simultaneously optimise both fertiliser and irrigation use efficiency in fruit and vegetable production

Specific challenge:

Fruit and vegetable production are often associated with excessive applications of fertiliser and irrigation with consequent environmental problems. Fertigation, fertiliser application in irrigation water, is becoming a mainstream technique for fruit and vegetable production. Fertigation combined with localised irrigation has the technical potential for precise and optimal management of both

nutrients and irrigation. However, farmers lack the management tools and procedures to effectively exploit this technical potential. Exploitation of this technical potential will enable farmers to reduce fertiliser and water use, and reduce negative environmental impacts while maintaining or enhancing production and product quality.

Scope:

Proposals should provide fruit and vegetable growers with tools and approaches to (i) precisely determine the amounts and timing of both fertiliser and irrigation requirements, or (ii) to identify any necessary adjustments to ensure optimal crop nutrition and water status. The tools and approaches should be useful for simple and complex fertigation systems where fertiliser is applied on the bases of rate and concentration, respectively. They should result in reduced fertiliser and water use, reduce nutrient losses to water bodies, ensure high yields, and optimise product quality in line with EU consumers' expectations. Solutions may be high technology (e.g. decision support systems, sensors) or agronomic approaches, or judicious combinations of both. Solutions should be practical, user-friendly, and both labour and cost efficient. Proposals should fall under the concept of "multi-actor approach", from the producer to the researcher, thus allowing for the adequate involvement of all stakeholders in the proposed activities. This will facilitate the rapid uptake of the cross-knowledge generated within the project.

Expected impact:

1) Ensure that EU society has a plentiful supply of high quality fruit and vegetable products produced with fertigation practices that considerably reduce nutrient contamination of waterbodies and optimise irrigation efficiency thereby meeting consumers' expectations of sustainable production of vegetables.
2) Provide EU fruit and vegetable growers with practical, easy-to-use management tools and management strategies for fertigation that will enable commercially viable and environmentally-friendly fruit and vegetable production
3) Ensure that the EU fruit and vegetable production is associated with sustainable land use by meeting the various requirements of the Water Framework Directive

7.2.4 ENABLING TECHNOLOGIES: ROBOTIZATION AND PRECISION HORTICULTURE

Robotization and precision farming is becoming increasingly important in horticulture. They can reduce and optimise the use of inputs, reduce environmental impact and increase sustainability of the cropping systems in all its aspects: social, environmental and economic. So this topic is related to most other research topics.

Fruit and vegetable production is labour intensive. Often the work is repetitive and in difficult (environmental) conditions. Labour availability in the EU is highly dependent on economic cycles, political regulations and societal issues. Overall, this introduces a significant level of uncertainty to fruit and vegetable growers which is negative, in the long term, for the economic performance of the sector. In the case of vegetable production, weed management and harvest accounts for the major part of the work. There is a need to develop technological solutions as well as management strategies to improve the labour efficiency. Three processes are accountable for the majority of labour input: pruning, fruit thinning and harvest. The tendency to mechanize pruning of the trees and fruit thinning is bringing about a significant reduction in the requirement for man power in these two operations. However, there is a need to further improve the processes and adapt the architecture of fruit orchards to these mechanical processes. However, the main need for improvement exists in the area of mechanization of harvesting. This operation has long been resisting attempts to mechanization that can maintain the objective of preserving high fruit quality. Projects that have sought a full-robotics solution have not reached a successful end. New attempts are needed to develop mechanical aids to fruit harvest. Also in greenhouse vegetable

production leaf pruning robots and harvesting robots are being developed. They need further development so that they can be used in other crops and other cropping systems.

Besides labour, robotization and precision horticulture can also enable the reduction and optimisation of the use of other inputs like water, fertilizer, energy, plant protection products, etc.

Research topics identified in this area are:

1. Increased labour efficiency in key fruit and vegetable production processes
2. Mechanization and robotization (pruning, thinning, weeding, harvest, post-harvest management etc.)
3. Precision Horticulture

Development of mechanical and robotic technical aids to hand fruit picking for a more efficient and safe harvesting

Challenge

Fruit production is labour intensive. Three processes, pruning, thinning and harvesting account for the major percentage of labour required in fruit production at the orchard level. On the other hand, availability of horticultural skilled labour is dependent on the economic cycle, political regulations and social factors.
Progress in mechanical pruning and thinning has already been made in the last years. However, attempts in the past to introduce robotics into fruit harvesting have not been taken up in commercial orchards for various technological reasons.
It is likely that it will not be possible to replace hand picking completely with technology. However, technical aids to hand picking and highly efficient fruit transfer to bins and dry bin filling with robotics and vacuum transport technology might help in making labour more efficient and safe.

Scope

With the technology available today a completely robotized solution for fresh fruit picking is still not a long way off. However, research that focuses on making fruit transfer from the hands of pickers, once the fruit has been detached, to the bin is needed. Technologies using vacuum transport of fruit, robotics to handle fruit once it has been detached from the tree and high efficient dry bin filling needs new or renewed attention. Research should focus in these areas: labour efficiency, worker safety especially linked to work-related diseases caused by highly repetitive tasks, to fruit quality (fruit free from blemishes due to punctures, contact pressure, etc.) and the adaptation of orchard architecture. Research will focus not so much in substituting for labour but in making it much more efficient and safe.

Expected Impact

Research should result in a fruit picking equipment and tools that assist hand picking of fruit making it more efficient and safe to workers. Relevant expected impacts are:

a) Equipment for fruit transfer from the tree to the bin once the fruit has been detached
b) Robotics that assist in fruit transfer from the tree to the bin
c) Highly efficient and blemish dry bin filling
d) Orchard pruning and training systems better adapted to mechanical equipment to assist harvesting.

Precision horticulture: integration of proximal sensing techniques and GPS

Specific challenge:

The use of applications based on GPS-technology is increasingly growing in horticulture. Initially, GPS-technology was used, and it continues to be used, for steering guidance. GPS-technology enables tractors and machines to drive on pre-defined lines without an operator. Currently, various types of sensors are being increasingly used in combination with GPS for mapping soil and crop conditions and precision application based on these maps. Sensors are available for soil monitoring (pH, %C, EC, …) crop monitoring (spectral and optical cameras) and yield determination (online weighing systems on harvesting machines). However, there is a need for an integrated system that brings all data of the different sensors and systems together. The potential of these systems is much higher if all data from all levels of crop production are linked together. By knowing about local variations within a field, opportunities are created for improving the use of nutrients, water and plant protection products resulting in better crop management and an optimized yield. Most of the previous work has been

conducted with cereal crops. Fruit and vegetable crops have great potential, but research is needed to develop the specific technology.

Scope:

The use of proximal or close sensing techniques is becoming increasingly important in horticulture, in the field but also in greenhouses. It is important that these technologies are adapted to vegetable crop production. Many of these sensors are used in agricultural crops but adaptation will be required for fruit and vegetable crops. For specific fruit and vegetable crops, identification of the most effective sensors and vegetation indices will be necessary, and procedures must be developed to effectively interpret the signals identified as being the most sensitive. In addition to GPS mapping for precision applications, there is potential for fixed position sensors to continually monitor a crop. The capture and management of the associated very large data flows and the development of relationships between sensor signals and crop performance and expected yield is well developed for cereal crops. Applying these developments to fruit and vegetable production will appreciably enhance input efficiency and reduce negative environmental impacts. It is essential that sensor data be processed and the outcome presented in practical user-friendly applications developed for specific groups of growers.
Research adapting close sensing technologies to vegetable production may include:

- Identifying sensors and indices most sensitive for individual species and relationships useful for crop management.
- Development of models that can identity relationships between data from different sensors
- Development of applications for farmers

Expected impact:

This research topic will increase the applicability of close sensing techniques based on GPS to horticulture, and contribute to increased automation of horticultural crop production
It will reduce the need for labour
It will reduce the environmental impact of inputs such as fuel, fertiliser, pesticides, etc.
It will enhance productivity and the quality of the produce

7.2.5 GREENHOUSE PRODUCTION

Although field production systems are still the most important part of the production area of fruits and vegetables, greenhouse production systems have been developing systematically. Depending on the climatic conditions, crops have been covered directly with foils, planted in tunnels, polytunnels, plastic greenhouse and finally, glasshouses. The two most important greenhouse production systems are: non-heated, mostly plastic, greenhouses which are more used in the southern European regions and heated greenhouse, mostly glasshouses, mostly used in the northern European regions where the need for climate management is higher (e.g. heating, cooling, (de)humidification and lighting). Greenhouse production is being developed technologically in all its aspect: specific genetic material is being developed, the most advanced biological control systems are applied in greenhouses, closed systems are developed to reduce inputs and automation and robotization has entered into the greenhouse production systems.

Greenhouses over Europe offer competitiveness and performance to growers and contributes to the supply of nutritious food and the economy of whole regions in Europe. Nowadays, greenhouse production systems face new challenges related to the specific context combining climate change and the increase in food demand. Indeed, the best case scenario is that global surface temperatures will increase by at least 2 degrees Celsius in the coming decades, thus leading to the modification of climate management in greenhouse and also the need for a reduction in the ecological footprint of human activities, notably agriculture. Moreover, the world population is expected to grow to 9.6 billion by 2050 (from 7.3 billion now), so that food production will have to increase by 70 percent, according to the Food and Agriculture Organization of the United Nations (FAO).

This means that - as most of the land available for food production is already being cultivated - greenhouse production systems will become more important. Innovative strategies or techniques that increase yields, improve quality, reduce primary resources usage and thus the ecological footprint have to be integrated into the greenhouse sector.

In this area, the identified research topics are:

1. Systems that integrates cultivation techniques and climate management based on plant behaviour and modelling
2. Developing and integrating new designs, equipment and materials to enhance production and quality
3. Managing inputs and outputs to increase efficiency

Innovative systems for crop and system management in greenhouses

Specific challenge:

In the particular context of combining climate change and increasing global food demand (due to population growth), fruit and vegetable production systems are facing new challenges. Considering the energy crisis (related to high energy costs) in the recent past, the area of greenhouse production has either remained stable or decreased in countries with low winter temperatures while it has strongly increased in areas where heating requirements are much lower. The energy scenario led to the establishment of two clearly distinct production models. On one side, Northern countries settled on soilless production systems in heated glasshouses, increasing performance and competitiveness, but the profitability depends mainly on the good management of greenhouse inputs, especially energy as it has high economic and ecological costs. On the other side, Southern or Mediterranean greenhouses adjusted to local conditions, with moderate investments and little (if any) climate control system besides natural ventilation; thus leading to suboptimal conditions for plant production and as a consequence lower yields than those from high-technology greenhouses. Most of them use plastic films as cover material. Gathering these facts, there is a need for the European heated and non-heated greenhouse crop sector to build innovative strategies or techniques that preserve yields, improve quality, control energy consumption and reduce their ecological footprint.

Some topics to study: (i) Cultivation techniques and climate management based on plant behaviour, (ii) Development and integration of new designs, equipment and materials to optimize production and quality, (iii) Input and output management to control environmental impact

Scope:

Proposals should contribute to improving climate and crop management considering energy management and real-time dynamic responses of plants. The achievement of a sustainable and efficient production system, both environmentally and economically, using LCA to identify the most critical factors is of high concern to improve yields and quality while reducing the carbon, nitrogen and water footprints. Available tools include (i) the optimization of the use of cultivation techniques and climate management tools taking into account plant physiology, the integration of new plant sensors and modelling, in order to refine our knowledge and propose decision making tools to steer the crop microclimate accurately; (ii) the development and integration of designs, equipment and materials for greenhouses that decrease thermal losses, increase light transmission, improve cooling, heating (de)humidification and lighting and reduce pest and disease pressure;. (iii) the use of new input sources, renewables, possibly incorporated in recycling loops and the regeneration or the re-use of outputs. Notably new energy sources must be considered aiming to reduce fuel dependency. A focus on CO2 management in greenhouses must be integrated to optimize CO2 use by plants (helped by increasing knowledge on plant physiology over daytime and in contrasting environments) and CO2 sources. An optimal pest and disease, water and fertilization management in intensive greenhouse crops are expected to have no impact on the environment and human health.

Proposals should combine topics to propose integrated projects including the following subjects: climate control and crop management (through appropriate pruning techniques, plant density, …)

based on plant models, cover materials (keeping in mind the need for extension of the shelf-life of cover materials, increasing light transmission, the use of refrigerant materials and transparent photovoltaic panels, …), semi-closed greenhouses, CO2 scrubbing from ambient air, low temperature heating, innovative (de)humidification techniques and equipment, supplemental lighting, recycling loops for nutrients, phenomics, robotics, …

Expected impact:

The European greenhouse vegetable production is a competitive sector known for its high quality production and performance. It contributes to the supply of nutritious food and to the economy of whole regions in Europe (as it is also a labour intensive sector). Considering the European context, projects' impacts are expected to improve the sustainability of greenhouse production, both economically and environmentally. The reduction of energy costs, and globally to input-output fluxes, is awaited with the objective to tend towards energy neutral, self-supporting greenhouses, as societal expectations about lowering the ecological footprint of greenhouse production are strong. Innovation transfers between heated and non-heated sectors are strongly expected.

HEADING	TOPIC	TIME PRIORITY	CHALLENGES ADDRESSED						
			COMPETITIVENESS	SUSTAINABILITY	CLIMATE CHANGE	FOOD SAFETY AND SECURITY	HUMAN HEALTH AND WELL-BEING	SOCIAL ECONOMY	FRUIT VALUE
Genetics									
	Breeding new high quality fruit and vegetable varieties meeting consumers' preferences and segmented market demands	2018-2019	x	x	x	x	x		
	Developing new breeding techniques to promote the valorisation and a better use of horticultural genetic resources	2018-2019	x	x	x	x	x		
	OMICS technologies for fruit and vegetable production management	2018-2019	x						
Sustainable Plant Protection									
	Minimization of residues and innovative plant protection methods	2016-2017	x	x		x			
	Innovative IPM practices with lower impact, lower residue and enhanced sustainability	2018-2019	x	x	x	x	x		x
	Improve soil suppressiveness for reduced pesticide input	2018-2019	x	x	x	x	x		x
	New spraying techniques	2018-2019	x	x		x	x		
	New quarantine diseases	2018-2019		x	x				
	Old and disrupting pest and diseases	2018-2019		x					
	European pests review and mitigation measures for market access	2020	x						

HEADING	TOPIC	TIME PRIORITY	CHALLENGES ADDRESSED						
			COMPETITIVENESS	SUSTAINABILITY	CLIMATE CHANGE	FOOD SAFETY AND SECURITY	HUMAN HEALTH AND WELL-BEING	SOCIAL ECONOMY	FRUIT VALUE
Efficient use of Primary Resources									
	Maintaining yield and quality of fruit and vegetable production under combined water and heat stresses	2016-2017	x	x	x				
	Optimizing nitrogen use efficiency and ensuring yields in fruit and vegetable production	2018-2019	x	x	x				
	Irrigation management for diverse fruit and vegetable species to optimise water use efficiency, production and product quality.	2018-2019	x	x	x				
	Fertigation management to simultaneously optimise both fertiliser and irrigation use efficiency in fruit and vegetable production	2018-2019	x	x	x				
Enabling technologies									
	Increased labour efficiency in key fruit and vegetable production processes	2016-2017	x						
	Precision horticulture: integration of close sensing techniques and GPS	2018-2019	x	x					
	Mechanization and robotics (harvest, thinning, pruning, weeding...)	2018-2019							
Greenhouse production									
	Innovative systems for crop and system management in greenhouses	2018-2019	x	x	x				

7.3 Research needs for Storage and Handling

7.3.1 Minimally processed fruits and vegetables

Any losses (quantitative or qualitative) that occur after harvest are particularly economically important given the costs incurred in production and management up to that point. There is a large range in perishability of fresh fruit and vegetables with storage life varying from days to months, and the technological challenges are equally diverse. Furthermore, retail of produce in minimally processed form is increasing due to added convenience for people coping with busy modern life styles, and this introduces yet further challenges and research needs.

Fresh minimally processed fruits and vegetables are important components of a daily diet. Fresh-cut and minimally processing of fruit and vegetables improves convenience, but increases the rate of degradation reactions of the product as a consequence of tissue wounding, and makes them more susceptible to attack by plant pathogenic microorganisms and possibly more conducive to survival and growth of food poisoning microorganisms (such as *Listeria monocytogenes* and *Escherichia coli)*. Raw material can harbour many microorganisms, which may be dispersed during washing, cutting or peeling prior to the sale of the fresh-cut products. Some methods have been developed for detection and quantification of microorganisms but there is still a lack of rapid, reliable and specific methods for the evaluation of quality in ready-to-eat fruits and vegetables during the production chain from pre to consumption.

The market for minimally processed vegetables has been well established, whereas the market for minimally processed fruits is still under development. The difference is first and foremost connected to economy. Preparation of vegetables at home is usually time consuming and consumers have high preference for ready to eat minimally processed vegetables, whereas fruit may be eaten as it is. Minimally processed fruit require special selection of raw product, have relatively short shelf-life, and their market is more vulnerable in the case of slowdown of the economy. However, there is potential to build the market by addressing specific groups of consumers: children at school, hospital patients, the elderly and occasional consumers (e.g. participants of conferences) etc.

In recent years, significant progress has been made in risk management, but to increase consumers' confidence, more work is needed in respect to optimizing quality of minimally processed fruit and balancing components in respect to health effects, thus creating the possibility of promotion using health claims. Safety aspects should be guaranteed not only by strictly adhering to available guides (e.g. on minimization microbial food safety hazards), but also by using specific indicators of temperature control, and/or micro-organisms development etc. Due to the usage of new combinations of products, it is necessary to establish the shelf-life of the products in terms of both safety and quality.

1. Minimally processed fruits and vegetables (quality and food safety aspects)

7.3.2 Minimizing produce contamination

Microbial contamination can increase the rate of deterioration of both fresh and minimally processed fruit and vegetables. Products may be contaminated at any point along the whole chain from farm-to-fork. The growing conditions, orchard/plantation management system (organic, integrated production, etc), plant protection program, storage, processing, packaging and handling conditions are all crucially important in this context. Survival and persistence of pathogenic microorganisms can be affected by climatic conditions and also by naturally occurring bacterial epiphytes and endophytes present in the soil and plants. Once fresh produce is contaminated, removing or killing the microbial pathogens is very difficult, especially when pathogens are internalized. In minimally processed fruits and vegetables no processing step is foreseen that ensures killing all microorganisms. Therefore, prevention of contamination is crucial to ensure their microbial safety. Contamination with spoilage or pathogenic

microorganisms increases during storage. They are the cause of food decay and reduce shelf life of fresh-cut fruit and vegetables, and potentially may be a source of food borne illnesses.

There are numerous threats concerning biological contamination. Food scares related to food borne microbial contamination cannot be entirely eliminated considering that occasional outbreaks have taken place in the past and may appear in the future, irrespectively of enforced legislation and strict control. The consequences are serious; previous cases have resulted in both deaths and significant disruption of trade, in some cases impacting negatively on groups of growers that are subsequently found to be completely unconnected with the incident. Contamination of the product may occur due to use of organic fertilizer, agricultural water, worker hygiene during harvesting and handling, transportation and storage. Threats are numerous and the most common include: *Listeria monocytogenes* (associated with raw vegetables), Salmonella (infected fresh produce and unpasteurized fruit juice), *Shigella spp*. (associated with shredded lettuce, potato salad, green onions, parsley and several non-vegetable products). Interplay of factors affecting microbial growth in foods still need extensive research, including measures to control pathogens. Use of competing positive microbes should be further investigated.

On the other hand, minimizing chemical residues on fruit and vegetables is a key priority in Europe, and minimizing chemical application during crop production has been considered in an earlier section. Post-harvest chemical use within the EU is limited; produce may be disinfected using general antimicrobials such as chlorine, hypochlorite, hydrogen peroxide and ozone, usually in the form of a water dip, although misting (hydrogen peroxide, ozone) or gas treatments (ozone) are used. The grape industry is still very reliant on sulphur dioxide pads. However there have been incidences of chemical residue detection above permitted levels; for example, chlorate and perchlorate residues were found above permitted levels (0.01 mg/Kg) in almost a quarter of samples tested by Stuttgart CVUA in 2012/13. Many of the samples tested originated outside the EU, and the origin of these residues was not confirmed. They were probably due to illegal pesticide use, but some may have originated from chlorine treatments. The development/improvement of disinfectant treatments that leave no chemical residues is an area that needs more research, especially with the increase in minimally processed produce.

1. Minimizing produce contamination (biological contamination) (chlorate, perchlorate, ...)
2. Minimizing produce contamination (chemical residues)

7.3.3 PACKAGING

Packaging is an important component of the food supply chain; packaging contains foods, protects it from the outside environment (gases, microorganisms, dust, etc.), can provide an environment to extend storage time, increases convenience, and delivers important information to consumers about the product, nutritional value, expiration date, etc. The traceability of the products and the safety of their use have become increasingly important.

There are many packaging systems available that extend shelf life, allow monitoring freshness, display information on quality, improve safety, and improve convenience. Among them active packaging, intelligent packaging, and smart packaging could be found. To fulfill traceability, the unique radio-frequency identification (RFID) technology can be used. The technology can identify individual items along the whole chain from farm to fork.

In several EU countries non-degradable plastics are dominating food product packaging, in particular in fruit and vegetable packaging. Given that recycling has become obligatory and is an effective way of decreasing environmental pollution, identification of environmentally friendly packaging solutions is a high priority. Thus the focus should now also be on packaging to extend shelf-life and reduce waste. This includes packaging that can provide a suitable modified atmosphere capable of slowing produce metabolism, but without causing damage even given the challenge of temperature changes during the

handling chain; packaging that can slow deterioration through technologies such as ethylene removal; intelligent packaging that can provide a signal to the consumer when the produce is in unsuitable conditions or at the end of storage life. New easy open packages developed within "Optifel" project (currently running) might be adapted to e.g. minimally processed fruit and vegetables. Innovative technologies in packaging should be part of sustainable development.

1. Information technologies in packaging in fruits and vegetables
2. New packaging to extend shelf life in fruits and vegetables and minimize environmental impact

7.3.4 IMPACT REDUCING TECHNOLOGIES

By-products from the processing of fruits and vegetables, traditionally considered as an environmental problem, are being increasingly recognized as sources of health promoting components. Pomaces such as grape, apple, carrot, beetroot and tomato are good sources of natural antioxidants including carotenoids, vitamins, and phenolic compounds. These components derived from agro-industrial production, may be used as functional food ingredients and/or for creating new value-added products. The recovery of natural antioxidants as e.g. polyphenols from apple pomace is a feasible important biotechnological application. Apple polyphenols as antioxidants have pro-health properties, exhibiting a wide range of pharmacological effects, such as antibacterial activity, antiviral activity and the inhibition of colon carcinogenesis *in vitro*.

So far, the fruit and vegetable processing by-products are utilized partially as animal feed (apple pomace and peels) or are composted and used as fertilizer. Temporary storage and handling of these wastes causes sanitary problems and is difficult logistically. Thus, their utilization as dietary supplements provides an attractive alternative to the processing enterprises. At the same time these by-products may have high content of residues of chemicals used for plant protection. However, with changes in production systems (organic, integrated), protection strategies and techniques (intelligent sprayers, e.g. CASA) which allow significant decrease of plant protection chemical use, chemical contamination will be less of a problem. Research is needed on valorization of various by-products as a source of pro-health components and their efficient and optimal utilization.

Studies in the UK carried out by the Waste Resources Action Programme (WRAP) have indicated that losses with the food supply chain for fruit and vegetables range from 5 – 25%[29]. The main cause of product loss is 'out-grading' against the customer's specification, but loss can also arise in the field, in storage and when packing. Furthermore, annually WRAP estimates that UK households waste 1.9 million tons of vegetables and 1.1 million tons of fruit, around half of which is avoidable (i.e. could have been eaten). It is then clear that it should be a high priority to reduce waste. WRAP concludes that in the UK waste could be reduced by relaxing the specifications of the retailers, improving management of and communication within the supply chain and technologies such as improved packaging. In such situation, waste management is an important issue. Improved technology of composting, using specifics for the material selective accelerators should be developed. The ideas of circular economy should become popular in the EU. The ideas of making resource use more efficient, reducing the production of waste, maximising the recycling of waste and identifying alternative business models should be of special interest.

1. Fruit and vegetable processing industry by-products valorisation
2. Fruit and vegetable chain waste management

7.3.5 ENABLING TECHNOLOGIES

[29] *WRAP study: http://www.wrap.org.uk/sites/files/wrap/WRAP%20Fruit%2015%20-%20final.pdf*

Nowadays, consumers require high quality products. In the case of fresh fruit and vegetables this requires the development/implementation of technologies capable of assessing quality/maturity at harvest and during grading, as well as improved handling and storage technologies. There is a particular need for non-destructive technologies to assess quality, detect disorders and predict storage life. Technologies that are currently being used or developed for commercial use include optical imaging, near infra-red, chlorophyll fluorescence. There is a need for technologies that can obtain information from deep within plant tissues.

Long-term storage of apples is a particular challenge. In this case it is essential that fruits are harvested at optimal maturity. Standard procedures to optimise harvest date include measurement of flesh firmness, background skin colour, chlorophyll content of skin, starch content, total soluble solids content and titratable acidity. However, even with these assessments, high variability is noticed during storage. This variability may be reduced by grading fruit for homogeneity before storage. Modern grading lines are able to grade fruits in terms of size, colour and sometimes also internal quality like total soluble solids content, firmness, etc. A number of new apple storage technologies have been/or are being developed. These include the post-harvest application of 1-methylcyclopropene to block ethylene response, and the use of low oxygen storage sometimes twinned with methods to detect low O_2 stress (Dynamic Controlled Atmosphere (DCA) using Chlorophyll Fluorescence sensors, ILOS (Initial Low Oxygen Stress) using initial low oxygen stress to reduce surface scald, Swinglos which uses periods of low O_2 stress, DCS, ACR, DFR, etc.)

The existing variability among country/regions, species and cultivars has to be taken into consideration for the optimisation procedures.

Modern storage technologies and non-destructive techniques have the potential to reduce energy use maintain the quality (firmness retention) and reduce the risk of some physiological disorder (e.g. superficial scald).

1. New storage technologies (e.g. improved DCA)
2. New technologies in grading and sorting (robotics, non-destructive quality measurements, ...)
3. Energy efficiently storage systems
4. Decision support system for storage and handling disorders: scald, bitter pit, internal browning among others

Innovative tools for maintaining fruit quality and improving shelf life ability

<u>Specific challenge</u>:

According to the FAO, global food losses of fruit and vegetables in Europe reach the level of 45%. More than half of them happen during postharvest. Major causes of postharvest losses in the supply chain are: improper fruit maturity/ripeness at harvest, poor initial quality, mechanical damage, decay, improper storage conditions (temperature management, excessive water loss, undesirable levels of O_2, CO_2, C_2H_4), and too much extended storage period. Talking about the total losses of food one should take into consideration food losses (which refer to a decrease in food quantity or quality in the early stages of the food supply chain, reducing the amount of edible food) and food waste (refers to discard of foods at the end-user level, representing a missed opportunity to food security and resulting in an unjustified environmental price). It can be assumed that some amount of fruits is wasted due to low quality (not meet the consumer demands and expectations). The consumer requires fruits with high nutritional value, free from disorders, diseases and pesticide residues and with better taste and shelf life ability. At the same time retailers and other players within the supply chain (from farm to fork) are looking for fruits with long shelf life, good for marketing but not necessarily bearing with high eating quality, which quite often makes the consumers unsatisfied. This is resulting in decreasing fruit consumption, which is one of the several factors that threatens fruit production in EU. On the other

hand, a diet, rich in fruit and vegetables reduces risks of several non-infectious human diseases (e.g. heart attack).

Due to decreasing fruit consumption, there is a need to find out consumer preferences for a fruit in general and particularly for apples. Questionnaires distributed in different EU countries might reveal consumer preferences for varieties and most important sensory attributes like aroma, firmness, colour, crispiness, mealiness, juiciness etc. For quality insurance and control advanced traceability methods must be implemented. High quality of fruits is the most important attribute that ensures long term fruit consumption.

The project should aim at increasing fruit consumption by an interdisciplinary research approach building a "trustworthy" fruit with high eating quality and free from disorders (especially internal which are not visible at purchasing stage). The latter aspect is particularly important since the risk of disorders' development is strongly enhanced by climate change and improper use of novel storage techniques and technologies.

Scope:

Proposals should provide growers/retailers with (i) improved new non-destructive technologies to assess the optimum harvest date for fruits, (ii) good indicators/indexes (including molecular markers) allowing to predict the class of the risk of low storability and shelf life ability, (iii) new strategies/protocols for innovative storage technologies to reduce the risk of developing of storage disorders and diseases (including systems/sensors for early detection), (iv) create a Decision Support System – DSS for a proper decision about harvesting and selling high quality fruits. The reduction of costs of storage and energy use by applying innovative storage technologies and proper modern equipment should be also taken into consideration. All proposed technologies will need to be sustainable (socially, economically and environmentally) and tailored to the expectations and needs of the different EU growers.

Expected impact:

1) secure EU society with a plentiful, regular and seasonal supply of the different fruit species and varieties thus allowing to maintain and improve its current dietary culture
2) provide EU fruit growers with applied, easy-to-handle storage management technologies, proper use and know-how to maintain profitable, environmental- and societal-friendly productions;
3) Increase the fruit consumption in Europe by delivering to EU consumer fruits with high quality features in terms of taste, nutritional value and better shelf life ability;
4) preserve EU environment through the implementation of innovative technologies for storage and post storage supply chain management which allow rational and efficient use of the energy and reduce the postharvest losses

HEADING	TOPIC	TIME PRIORITY	CHALLENGES ADDRESSED						
			COMPETITIVENESS	SUSTAINABILITY	CLIMATE CHANGE	FOOD SAFETY AND SECURITY	HUMAN HEALTH AND WELL BEING	SOCIAL ECONOMY	FRUIT VALUE
Minimally processed fruit and vegetables									
	Minimally processed fruit and vegetables taking into account quality and safety	2018-2019	x			x			
Preventing produce contamination									
	Input contaminants (chlorate, perchlorate, ...)	2020				x			
	Biological contamination (Lysteria, E. Coli ...)	2018-2019				x			
Packaging									
	New technologies in packaging	2020	x						
Impact reducing technologies									
	By-product valorisation	2020		x					
	Waste management	2020		x					
Enabling technologies									
	New storage technologies (improved dca)	2016-2017	x		x	x	x		
	New technologies in grading and sorting (robotics, non-destructive quality measurements, ripening measurement)					x			
	Energy efficient storage systems	2018-2019		x	x			x	
	Decision support system for storage and handling disorders: scald, bitter pit, internal browning, ...	2018-2019	x			x			

7.4 Research needs for Distribution

7.4.1 Category And Supply Chain Management

For the distribution of fresh products, control of the logistics (warehousing, transport …) is an essential element in competitiveness. It is also a crucial factor for the maintenance of quality to the point of reaching the consumer. Improvement in performance for example by temperature management and reduction of mechanical damage are certainly feasible and should be prioritized.

The relationships between suppliers and customers are more and more formalized through specifications laying down the obligations of both parties. Some of these specifications have international validity and are universally recognized. More recently, a realization of the importance of the environmental dimension of production and distribution has led to develop specific standards (carbon impact, impact on water and biodiversity) which require methods such as the analysis of life cycle. The supply chain includes fruit and vegetable products from different origins and requiring very different handling technologies. Knowledge of the environmental impact of supply chains is an issue of increasing interest to consumers and one that deserves priority when considering the sustainability of supply chains.

The relations between actors in production and distribution are rendered difficult by the diversity and the volatility of the markets which encourage opportunistic behavior. Improving the dissemination of information throughout the chain (situation of markets, technical and quality specifications of products, historical time/temperature at each step) can contribute to improve the efficiency of the value chain and the satisfaction of the consumer by a better response to the constraints of the different actors in the chain.

1. Improvement of fruit and vegetables logistics efficiency
2. Standardization of evaluation/audit methodology for whole chain standards (EUREP/GAP, Carbon foot print, water foot print, …)
3. Information exchange across the fruit and vegetables value chain

7.4.2 Preservation Of Quality Across The Chain

Quantitative and qualitative losses occur at all post-harvest stages in the life of the product. This loss of quality often leads to disappointment for the consumer and generates waste. Both aspects could be limited by improved information to the consumer on how to handle produce and by better product management by stores and retailers. In all these cases technologies to improve quality maintenance would have a positive contribution.

1. Reducing the gaps between the links (training, education, communication, logistics, devices, varieties, shorter transit time)
2. Point of sales technologies to extend post-harvest shelf life (packaging, water spray, etc.)

7.4.3 New Added Value

In a context where the consumption of fresh fruit is made more difficult by modern lifestyles (an increase in eating “on the move” and outside the home), the products on offer should also evolve, toward modes of presentation that are better adapted to these lifestyle changes. The study of new types of packaging, of more ready-to-eat products and new modes of distribution are all important aspects with potential to promote the accessibility of fresh whole and prepared fruit especially for young consumers who buy less than their elders.

1. New added value products (varieties, packaging, convenience, food services, vending, …)

HEADING	TOPIC	TIME PRIORITY	CHALLENGES ADDRESSED						
			COMPETITIVENESS	SUSTAINABILITY	CLIMATE CHANGE	FOOD SAFETY AND SECURITY	HUMAN HEALTH AND WELL BEING	SOCIAL ECONOMY	FRUIT VALUE
Category and Supply Chain Management									
	Logistics efficiency	2020	x					x	
	Standardization of evaluation methods for whole chain standards (EUREP/GAP, Carbon foot print, water foot print, …)	2018-2019	x						
	Information exchange throughout the supply chain	2020	x					x	
Preservation of Quality Across the Chain									
	Reducing the gaps between the links (training, education, communication, logistics, devices, varieties, shorter transit time)	2020	x			x		x	
	Point of sales technologies to extend post-harvest shelf life (packaging, water spray, temperature)	2020	x			x			
	Management of sanitary and phytosanitary risks at various stages of the chain	2020	x	x				x	
	Control of quality in distribution	2020	x			x		x	
New added value									
	New added value products (varieties, packaging, convenience, food services, vending, …)	2018-2019				x		x	x
	New ranges of fresh fruit prepared (fresh cut)	2020				x		x	x

7.5 Research needs for Consumers

7.5.1 Better Consumer Knowledge

Continuous decreasing consumption of fruit and vegetables is most probably due to many causes. Amongst others, lack of knowledge, lack of adequate offer, cost of fruit, quality and consistency of quality, convenience and safety perception have been cited as putative reasons. Most of these reasons are based on a profound lack of knowledge on the part of the consumer as well as actors in the chain about attitudes of behaviour and preferences of consumers. Better understanding of consumer preferences would contribute to understanding the potential causes and would allow for efficient strategies to help the entire chain.

The criteria for consumer choices are multi factorial. They are based on concrete elements (shape, color taste, texture, etc.) and on elements that are more symbolic (image, cultural references). The social context (modes of life, advertising) and the market environment are also important as they guide the choice of the place of purchase and the modes of presentation of products (packaging, modes of preparation). The studies of image aim to better understand the influence of these determinants.

Beyond the studies of image, it is essential to improve our understanding of the behavior of consumers in the purchase situation. Often there is a lag between the intentions and the reality of practices which are also determined by factors external to the consumer. Price level, which depends on the relationship between supply and demand influences the market environment. The evaluation of the willingness to pay of consumers by the methods of experimental economics is a means of evaluating the addition of price that a consumer is willing to pay for such or such characteristic (physical or symbolic, linked to the product or to its mode of production and distribution).

The supply chain of fruit is subjected to a volatility of supply and demand due in particular to the impact of climatic conditions on products consumed and to short storage capacity. There is currently a lack of accurate information on the impact of variations in the supply and demand on the formation of prices and on their consequence on consumer behavior. Similarly, the possibilities of substitution between fruits in the consumers' choices are poorly understood. Very quantitative analyses based on data from panels of consumers could serve as the basis for this type of investigation.

1. Better fruit and vegetable consumer knowledge
2. Consumer perception
3. Consumer behaviour in point of sale
4. Fruit and vegetables supply/ demand relationships and consumer behaviour

7.5.2 Consumer Awareness and Education

In spite of existing abundant evidence of positive consequences of eating fruit and vegetables to human health and well-being and public and private campaigns advocating for increased fruit consumption, this is not translated into increased fruit consumption. This indicates insufficient consumer awareness of benefits of fruit consumption.

EC legislation on nutritional and health claims regulates what information manufacturers of foodstuffs can publish in foodstuffs package. Unfortunately, it is difficult for fruit and vegetables to apply for health claims for various reasons (i.e. differences amongst the produce). Information on nutritional and health claims related to fruit and vegetables is incomplete and scattered in different scientific publications and not readily available to users. Research is needed to complete, compile and disseminate information on health claims for fruit and vegetable products.

1. Nutritional and health claims

2. Communication strategy and information tools

Repositioning the fruit and vegetables sector within its nutrition and health claims assets

Specific challenge:

Over the last decade, the consumption of fresh fruit and vegetables is experiencing an alarming decline. According to the Freshfel annual consumption monitor, the equivalent of one piece of fruit or vegetable per capita per day was lost during the last decade. While consumers are aware of the benefits of a healthy diet, rich in fruit and vegetables, they don't convert this awareness into concrete action and eating habits. At a time of rising obesity and the rapid growth of non-communicable diseases resulting from inappropriate lifestyles and diets, stimulating healthy eating habits rich in fruit and vegetables is much needed. However, the fragmentation of the sector and the lack of significant resources for marketing and research, weaken the sector's position to compete with other food products.

According to the World Health Organisation (WHO), low intake of fruit and vegetables is one of the main preventable/modifiable diet-related risk factors of developing NCDs. While continued action to decrease the intake of fat, salt and sugar is important, more coherent and concerted efforts are necessary to promote and support the consumption of whole or minimally processed foods such as fruit and vegetables, which constitute a major key of healthy and sustainable diets. The European Union has in fact in recent years embarked in new initiatives to better position fresh produce towards consumers through an increased promotion budget or building up a new scheme of fruit and vegetables distribution in schools (the EU School Fruit Scheme) to get the youngest to discover and be acquainted with the taste and texture of fresh fruit and vegetables.

In the framework of the current legislation on nutrition and health claims made on food (Regulation (EC) No 1924/2006 and Regulation (EC) No 432/2012), foodstuffs can now advocate their nutritional or health properties to consumers following the list of claims (and in accordance with its specific conditions) identified by the European Food Safety Authority. While information sustaining claims are available in several Member States, and despite well-known international recommendations (i.e. WHO minimum intake recommendation of 400 g/capita/day), nowadays there is not a general EU advice on the benefits of consuming fresh fruit and vegetables at the European level. Unfortunately, it appears that European consumers are not getting all relevant information on the importance of consuming fresh produce for their wellbeing.

More coordination is therefore needed to aggregate the information, evaluate research and explore new opportunities resulting from this legislation. European consumers could take a greater benefit of the existing scientific evidence if a pan European initiative would review existing and new studies in this respect. Information should become widely accessible for the sector, for health practitioners and nutritionist as well as for consumers in an easily accessible database.

Scope:

The proposal would aim at:

- reviewing and consolidating existing and new studies and information on nutrition and health properties of fruit and vegetables
- inventorying scientific studies available to sustain health or nutrition claims and identify gaps in research that prevent new claims to be submitted and available for the sector
- building a pan-European database to facilitate access to EU authorised health and nutrition claims for the sector

- set up without further delay a message (or number of messages) for the attention of consumers that would underline the health benefits of a diet rich in fresh fruit and vegetables. These messages should be put to the use of our sector for communication and information to the consumers at large without any restrictions.
- conducting consumers research to enhance communication strategies for the sector to take the most benefit of its nutritional and health benefits

Expected impact:

Upon development of a project, it should lead to the following expected impacts:

- Better position the fruit and vegetables category in a very competing food environment
- Remedy to the decline of consumption and build on existing awareness of the health benefits of consuming fresh fruit and vegetables
- Assist the sector to take the full benefit of the new regulatory framework on claims and have better consumer insight on messages that would contribute to a sustainable growth of the consumption and drive consumers into a healthy diet, rich in fruit and vegetables

HEADING	TOPIC	TIME PRIORITY	CHALLENGES ADDRESSED						
			COMPETITIVENESS	SUSTAINABILITY	CLIMATE CHANGE	FOOD SAFETY AND SECURITY	HUMAN HEALTH AND WELL-BEING	SOCIAL ECONOMY	FRUIT VALUE
Better consumer knowledge									
	Better fruit and vegetable consumer knowledge	2018-2019					x	x	x
	Consumer perception	2018-2019					x	x	x
	Consumer behaviour in point of sale	2018-2019					x	x	x
	Fruit and vegetables supply/ demand relationships and consumer behaviour	2018-2019	x				x	x	x
Consumer awareness and education									
	Nutritional and health claims	2016-2017					x		
	Communication strategy and information tools	2020					x		x

8 THE STRENGTHS OF R&D ON FRUIT AND VEGETABLES IN EUROPE

8.1 ROLE OF EUFRIN IN THE FRUIT CHAIN

The onset of the EU Framework Programmes in the early 90s prompted fruit scientists (geneticists, breeders, fruit physiologists, tree physiologists, ecophysiologists, nutritionists, pathologists, agricultural engineers, etc.) to realize the need and opportunity to cooperate and coordinate research in the fruit sector, if they were to be able to successfully answer EU-FP calls. The scope, complexity, number of partners that needed to be involved in a successful bid was a strong driver to the formation and/or consolidation of partnerships among researchers and research institutions. Such coordination efforts led to several successful projects covering a broad range of important topics crucial for the fruit sector: resistance to biotic stresses (Dare, Sharco), fruit quality (Hidras, Isafruit), tree physiology (Isafruit), human health (Flavo) and more recently climatic changes (Climafruit, FruitBreedomics). Most of these projects have been focused on the main two fruit species apple and peach, but also on berries (EuroBerry, EUBerry, Climafruit), cherries (COST Action FA1104), apricot (Sharco) and pear (Erwinia), among others.

Most if not all of European research projects were spawned within EUFRIN, an informal voluntary network created in 1992 gathering university departments and research institutes that specialize in research, development, and extension on temperate fruit crops and which are based within countries of the European Union, Switzerland, and Eastern Europe. The main objectives of EUFRIN are to enhance and facilitate coordinated research, development and technology transfer focused on aiding sustainable production of quality fruit (products) and to establish and improve cooperation between those involved in fruit R&D.

EUFRIN has a Board which typically includes two country representatives and the Chairpersons of the various Working Groups. The Board meets once a year, to discuss an agenda focused towards the exchange of information on fruit research, which has included over the years also the organization of international workshops and conferences but mainly by organizing regular meetings of Working Groups dedicated to major topics such as Apple and Pear variety testing, Postharvest and Fruit quality, Fruit thinning, Plum and Prune, Soft fruit, Spray application techniques (WG-SAT), Stone fruit variety evaluation, Sustainable fruit production to minimize residues. Several of these WGs have been instrumental for successful EU bids, such as COST Actions and RTD Programs in specific areas.

Besides the leadership provided in coordinating fruit-research in Europe (see below), EUFRIN is involved in providing expertise to the fruit chain via advisory services to growers and support to suppliers, marketing desks and retailers. Most of the WGs of EUFRIN meet once a year, and participation to them is open to any researcher active in the specific field. They have strong interaction with chain stakeholders, such as in the case of the chemical or nursery industries. Some of the WGs adopt common protocols, so that results can be compared across different environments and used to deliver to growers technical consulting suited to their local condition. This international, coordinated activity, in turn, has led to the recognition of these Working Groups as a de-facto authority in Europe on specific fields by relevant industry stakeholders. For example, some of these Working Groups have been carrying out ground-breaking work in establishing protocols and memoranda of understanding between interested partners that have been widely adopted (e.g. variety evaluators and nurseries owning exploitation rights).

Further examples of the EUFRIN legacy include the widespread uptake of European research outcomes on a global scale, which has allowed significant technical improvements in the fruit chain worldwide. Witness to this are the adoption of high density planting systems; new cultivars; spray technology;

integrated fruit production; quality assurance programs; non-destructive technology for quality assessment; etc.

8.2 ROLE OF EUVRIN IN THE VEGETABLE CHAIN

EUVRIN is an informal, voluntary organization of research institutes or research institutes departments that specialize in research, development, and extension on vegetable production, which are based within countries of the European Union. It was set up and held its first meeting in Brussels on February 1 2016, attended by representatives of Austria, Belgium, Cyprus, Denmark, Estonia, France, Germany, Italy, Lithuania, Netherlands, Norway, Slovenia, Spain, Sweden, Switzerland and United Kingdom. The current number of research institutes stands to 50 (www.EUVRIN.eu).

Its goals are to establish and improve cooperation between vegetable R&D institutes and teams within Europe; to promote the exchange of information on vegetable research, development, in particular via annual or biennial meetings of its Board and Specific Working Groups; to organise international workshops/conferences; to enhance and facilitate coordinated research, development and technology transfer, focused on aiding sustainable vegetable production; to enhance joint bids for funding of R&D in international and European programs (e.g. Interreg, Cost actions; Horizon 2020, etc.); to conduct surveys on the changing priorities in vegetable R&D within the participant countries; and to establish and update a research agenda and communicate it to national and international, European authorities.

The Board of EUVRIN is being constructed and consists of up to two voluntary representatives from each member country and the chairpersons of each of its Working Groups. At the founding meeting, 5 working groups were established: IPM for vegetables, Fertilisation and irrigation, Genetic resources and breeding; Greenhouse and Quality; and Value creation in the chain. The EUVRIN management team and EUVRIN working groups have contributed significantly to the actualisation of the strategic research and innovation agenda for fruit and vegetables.

The wide presence at the founding meeting and consecutive interest of nearly 500 scientists from all over Europe shows that there is need for further developing EUVRIN as an authority in European vegetable research.

8.3 LIST OF THE MAIN SUCCESSFUL EU-PROJECTS

Over the years, a number of expressions of interest have been put forward by EUFRIN and the vegetable research community, as prompted by the EU, for consideration and possibly inclusion in the calls published by the Commission. On the other hand, EUFRIN WGs have also been able to answer successfully to several of these calls. A short description of some (but not all) of the main projects that have been awarded over the years is given below as an example of the capacity of EUFRIN and the vegetables research community to generate successful applications.

8.3.1 D.A.R.E. (DURABLE APPLE RESISTANCE IN EUROPE): 1998-2002

An integrated EU project focused on sustainable resistance of apple towards scab and powdery mildew. It included the characterization of the resistance in local and old European cultivars and also assessed the variability of the pathogens (mainly scab) all over Europe. Its main aim was to decipher the genetic architecture of this resistance.

8.3.2 EU-ROTATE_N PROJECT 2003-2006 (FRAME PROGRAM 5). DEVELOPMENT OF A MODEL BASED DECISION SUPPORT SYSTEM TO OPTIMISE NITROGEN USE IN HORTICULTURAL CROP ROTATIONS ACROSS EUROPE.

The overall aim of this project was to develop and evaluate a novel model-based decision support system to optimise nitrogen use in both conventional and organic vegetable rotations across Europe. This will help Member States to: a) Minimise hazards to the environment by adopting consistent approaches to improved efficiency of nitrogen use for different production systems and climatic regions of Europe. b) Optimise production of quality horticultural crops while enhancing the economic sustainability of horticultural production within the EU. Most fresh vegetables within Europe are produced in intensive rotations, which rely heavily on large inputs of nitrogen from fertiliser or organic sources to maintain the yield and quality of produce demanded by its customers. Most field vegetable crops use nitrogen inefficiently and often leave large residues of nitrogen in the soil after harvest, which can cause irreparable damage to soil, water and aerial environments. However, recent research has shown that these environmental impacts can be reduced without loss of yield or quality by improved design of rotations and by more closely matching nitrogen supply to the demands of individual crops. This project exploits these and other recent discoveries by developing a flexible integrated decision support tool, based on models and databases for nitrogen management and rotational planning in conventional and organic and other low input production systems. The EU-Rotate_N project involves 9 partners from 6 different countries.

8.3.3 HiDRAS (High-quality Disease Resistant Apples for a Sustainable Agriculture): 2003-2007

A collaborative effort between 11 European groups aimed at the identification of genetic factors controlling fruit quality, it featured an innovative approach based on the phenotypic and molecular characterisation of a large number of related genotypes. New software was developed to fully exploit genotypic, phenotypic and pedigree data, with the aim of identifying fruit quality QTLs and to follow the transmission of their alleles along the pedigrees. Consumer preferences were accounted for, to identify the quality parameters that determine the success of a new apple variety in different European countries.

8.3.4 FLAVO (FLAVOnoids in Fruits and Vegetables: their impact on food quality, nutrition and human health): 2005-2007

This targeted project (STREP) focused on fruits with high flavonoid contents which are widely available to European consumers: apple, grape and strawberry, together with their derivatives cider, wine and compotes. The FLAVO project aimed to provide methods and tools to monitor the flavonoid content in fruits and vegetables so as to optimise their beneficial effects on health. It covered five complementary areas:

1. Determining the optimum sources and doses of flavonoids for health,
2. Developing tools for the breeding of “improved” fruits and vegetables,
3. Developing production techniques to optimise the flavonoid content,
4. Studying consumer behaviour towards new products,
5. Disseminating results to stakeholders and information for consumers.

8.3.5 ISAFRUIT (Increasing fruit consumption through a trans disciplinary approach leading to high quality produce from environmentally safe, sustainable methods): 2006-2010

A European Integrated Research Project focused on the entire fruit chain, following a fork-to-farm approach. The strategic objective of ISAFRUIT was to increase fruit consumption, searching the improvement of health and well-being of Europeans and their environment, by taking a total chain approach, identifying the bottlenecks and addressing them by consumer-driven preferences. ISAFRUIT activities focused on:

1. Consumer driven and responsive supply chains,

2. Fruit and human health,
3. Improved appeal and nutritional value of processed fruit,
4. Improved quality, safety and sustainability,
5. Pre-harvest chain quality and sustainability,
6. Genetics of fruit quality.

8.3.6 EU-SOL. HIGH QUALITY SOLANACEOUS CROPS FOR CONSUMERS, PROCESSORS AND PRODUCERS BY EXPLORATION OF NATURAL BIODIVERSITY (2006-2010)

Strategic objectives addressed by EU-SOL:

1. To extract the under-exploited natural biodiversity present in Solanaceae to improve consumer-driven and environmentally-directed quality of tomato fruits and potato tubers.
2. To map, isolate and characterize genes responsible for quality traits and to dissect the molecular
3. Mechanisms underlying these traits by application of state-of-the-art knowledge and innovative technologies.
4. To assemble these genes within new elite genotypes to boost our knowledge and provide a blueprint for novel high quality varieties to be developed by EU breeding companies.
5. To coordinate and integrate breeding research for quality traits, to provide training in innovative technologies, to disseminate the results and to transfer knowledge and technologies to industry.
6. To participate in the international tomato genome sequencing initiative that will tie European
7. Solanaceae research and innovation into the full global activities in this area. This is of pivotal importance for Europe.

To create a model for how world-wide scientific collaboration can lead to innovative research that can set the road map on how to improve global food security related to a wide variety of other crop plants. EU-SOL is a network of plant scientists from universities, research institutes and industry within the EU, its partner countries Bulgaria, Israel and USA and INCO countries Westbank, Morocco, Argentina, Brazil and South-Africa.

EU-SOL focuses on the development of high quality and healthy tomato and potato varieties with improved consumer-, processor- and producer-directed traits. The consortium brings together expertise across a wide variety of disciplines across the EU – from taxonomy to molecular biology to consumer integration. Quality and wholesomeness of food and food products are two issues addressed prominently by society especially in relation to obesity (and atherosclerosis), the most important cause of cardiovascular disease, age-related diseases, such as cancer and diabetes and to the increasing preference of consumers for ‘regional’ and ‘niche’ food specialties. Additionally, producers are challenged by constraints in plant architecture and development such as fruit set and tuberisation.

The **strategic objectives** of EU-SOL are to understand the factors that affect consumer-driven and environmentally-directed quality of the two most important vegetable products in the EU, tomato fruits and potato tubers, both belonging to the Solanaceae. To this end, EU-SOL will attempt to dissect the genetic and molecular components that control these quality traits by applying state-of-the-art knowledge and technologies. EU-SOL particularly focuses on mapping, isolation and characterization of genes responsible for traits important for consumers and processors (health, nutrition, flavour, fragrance, soluble solids, texture, colour, shelf-life, starch, chipping quality) as well as for producers (plant architecture, fruit set and tuberisation) and the mechanisms underlying these traits (control of gene activity, regulatory networks). Important goals are to understand the factors that affect tomato and potato architecture and fruit and tuber composition, to acquire knowledge of carbon and nitrogen acquisition, partitioning and allocation during fruit and tuber development, and to identify the key genes involved. Assembly of these genes within new genotypes will boost our knowledge of the factors that control quality and provide a blueprint for novel high quality varieties to be developed by EU breeding

companies using efficient and rational breeding strategies based on marker-assisted breeding and genetic engineering that exclusively use natural plant genes.

8.3.7 COST ACTION 924: ENHANCEMENT AND PRESERVATION OF QUALITY AND HEALTH PROMOTING COMPONENTS IN FRESH FRUITS AND VEGETABLES

The main objective of this Action was to enhance and preserve fruit quality, safety and the amount of nutritional and functional components in fresh fruits and vegetables in an integrated approach from orchard to consumer with special attention to organic growing.

The work programme was organised in different working groups:

WG1: Improvement of the agri-food chain in terms of quality, healthiness and safety

WG2: Postharvest physiology and metabolomics: the interaction of postharvest scenarios with

WG4: Non-destructive methods for quality assessment

WG5: Modelling as a tool for integration and management of the whole chain

8.3.8 COST-ACTION 864: POMEFRUITHEALTH. COMBINING TRADITIONAL AND ADVANCED STRATEGIES FOR PLANT PROTECTION IN POME FRUIT GROWING: 2006-2011.

COST Action 864 is a network of plant protection specialists dedicated to gaining a deeper understanding of the major disease and pest constraints on apple and pear. Its aim is to develop integrated and sustainable orchard systems that deliver high-quality, healthy pome fruit to European consumers. Ecologically-sound agricultural practices will be promoted. Tackling existing, chronic problems as well as emerging threats from invasive and spreading of diseases will be the central theme. This Action networks bacteriologists, entomologists, epidemiologists, biochemists, microbial ecologists, molecular biologists, mycologists, tree breeders, national plant protection agencies and industry with the aim of integrating their efforts to design holistic pome fruit health management systems.

8.3.9 COST ACTION 863: EUROBERRY. TOWARD AN ORGANISATION OF THE INTEGRATED RESEARCH OF BERRIES.

The main objective of the Action was to improve the quality and production of berries to benefit health of the consumers and maintain profitable European production using sustainable systems. By using an interdisciplinary approach, the programme focused on selected topics of major importance for the European berry production system and quality control: genomics, variety evaluation, nursery production system, plant physiology and culture management, health for the consumer. The EUROBERRY Cost action has been at the basis of the new European project EU-Berry.

8.3.10 SHARCO (SHARKA CONTAINMENT IN VIEW OF EU EXPANSION): 2009-2012

The concept of SharCo is to combine prophylactic and genetic solutions to prevent or limit the spread of the sharka disease (caused by PPV). The project scope covers the entire chain from planting material (seedlings, scions …) production to orchard management. It addresses all concerned stakeholders, breeders, nurserymen, fruit producers, and plant protection services with relevant outcomes including respectively resistant varieties, management guidelines, cultivation guidelines, optimised survey and detection methods and tools.

8.3.11 CLIMAFRUIT (2009-2013)

Climafruit is a regional project which aims to establish transnational cooperation between research institutions and the North Sea Region (NSR) berry fruit industry in order to maximize the implementation of innovative technologies. The project will produce methods to reduce the carbon footprint of the industry, superior plant material and future production strategies better suited to the NSR climate, as well as a virtual Soft Fruit Climate Change and Environment Centre, ensuring the continuous uptake of methods by the berry fruit industry. As a first output, a new transnational cultivar trial was established

across the 5 partner countries and considerable activities were carried out on increasing the knowledge on sustainability of berries. Focusing on adaptation strategies, studies were carried out to determine the potential impact of climate change on fruit quality.

8.3.12 N-TOOLBOX. TOOLBOX OF COST-EFFECTIVE STRATEGIES FOR ON-FARM REDUCTIONS IN N LOSSES TO WATER. 2010-2012 (FRAME PROGRAM 7)

The overall aim of this project was to develop a "toolbox" of cost-effective technologies to be implemented at the farm level to protect water from nitrate pollution. The project focus on the identification of system-specific solutions that can be incorporated into national action programmes to achieve the objectives of the Nitrates Directive. This new infrastructure is known as N-TOOLBOX and consist of a) a catalogue of innovative and cost-effective technologies for reducing N losses from agricultural systems, and b) an enhanced N management decision support tool for use at the farm level. Within the N-TOOLBOX project, arable and vegetable production systems will be the focus of case studies where the N-TOOLBOX is used as an advisory system for farmers. In this case, NDICEA will be the decision support tool used in the toolbox. N-TOOLBOX activities target/focus on 4 annual cropping systems that have been flagged as contributing significantly to nitrate pollution within the EU. The N-toolbox project involves 4 partners in 4 countries.

8.3.13 AGROBIOFILM: DEVELOPMENT OF ENHANCED BIODEGRADABLE FILMS FOR AGRICULTURAL ACTIVITIES, 2010 -2013.

The aim of the project was to develop a new biodegradable agricultural mulch film more environmentally friendly (i.e. biodegradable in soil without containing a high content in fossil carbon); to be compliant with common farming methods; and to match or improve crops performance as expected in the case of conventional plastic films and other biodegradable mulch films available in the market. The new improved biodegradable film was successfully produced and tested on four selected crops (muskmelon, bell-pepper, grapevine, strawberry open field and strawberry in greenhouse). The Agrobiofilm project included three SME's and five RTD's and four end-users.

8.3.14 FRUITBREEDOMICS (AN INTEGRATED APPROACH FOR INCREASING BREEDING EFFICIENCY IN FRUIT TREE CROPS): 2011-2015

The aim of FruitBreedomics was to provide the European fruit tree sector with cutting-edge breeding tools for the efficient and accelerated creation of new apple and peach varieties with excellent fruit quality characteristics, improved resistances to diseases and pests, and that can be grown in sustainable agriculture systems in the context of climate change. A major breeding tool to be developed was a validated pipeline for Marker Assisted Breeding and its implementation in ongoing commercial breeding programs. Towards this, the efforts were directed to improve our understanding of the genetics of some major horticultural traits, develop innovative research tools to accelerate the breeding cycle, and efficiently find marker trait associations in breeding and GeneBank germplasm. Additionally, the project aimed at increasing the accessibility of breeders to the genetic diversity present in GeneBank germplasm collections, thus contributing to widening the genetic basis of cultivated fruit trees. The collected data were to provide precious genetic information on the pool of genitors and founders to be used in future breeding programmes. FruitBreedomics used a multidisciplinary approach that included genetics, genomics, ecophysiology and bioinformatics, and liaised international partners with complementary expertise. From its start, the consortium aimed at setting up a collaborative European network of breeders, GeneBank curators and industry representatives with the aim of rapidly and widely disseminating and implementing the obtained results among all interest European stakeholders.

8.3.15 INTERVEG. ENHANCING MULTIFUNCTIONAL BENEFITS OF COVER CROPS – VEGETABLES INTERCROPPING. 2011-2015 (EU-CORE ORGANIC II, ERA-NET).

The project aimed at verifying if the introduction and proper management of intercropping in vegetable production systems allows comparable yields and produce quality in comparison to the sole cropping systems, reducing the use of auxiliary, off-farm, inputs (i.e. plant protections products and fertilizers) and non-renewable energy consumption (i.e. fossil fuel for mechanical weeding). The cover crops – vegetables intercropped farming systems should then perform better in terms of environmental impact and profitability due to production costs reduction. This hypothesis was tested in a range of European areas where open field organic vegetable production is a relevant activity. Field experiments were carried out in four CORE Countries (IT, DK, DE and SLO) involving 8 partners of 5 CORE countries.

8.3.16 COST ACTION 1104: SUSTAINABLE PRODUCTION OF HIGH-QUALITY CHERRIES FOR THE EUROPEAN MARKET: 2012-2016

This Action aims at creating a dynamic network of scientists and other professionals conducting research to improve sweet and sour cherry production in Europe, the main cherry producer. Cherries are highly appreciated fruits for their taste and nutritional properties. Their production is economically important for many fruit growers in almost every European region but there is a need for coordinated research. Therefore, this network will address all research aspects related to cherry production, commercialisation, and consumption. It will be multidisciplinary and will involve scientists working in the fields of plant breeding, genetics, genomics, agronomy, physiology, phytopathology, entomology, microbiology, post-harvest technology, and socio-economics. A special emphasis will be placed on key EU priorities such as the promotion of sustainable agriculture and adaptation to climate change.

8.3.17 MARS (2013-2015)

Sharka, caused by the Plum Pox Virus (PPV), is the most devastating disease affecting stone fruit trees in Europe. In order to respond to this critical situation, the FP7-funded SharCo project (2009-2012) devoted a significant part of its efforts on the development of first-generation PPV resistant plant materials, guidelines for new plantings, and molecular tools for the implementation of marker assisted selection (MAS) in apricot breeding programs. The first steps in establishing MAS were achieved in SharCo but presented some limitations that hampered the EU-wide implementation of a high throughput MAS approach.

In this context, the MARS project (for Marker Assisted Resistance to Sharka), boosted the production of sharka resistant stone fruit cultivars by transferring the efficient and reliable procedures of MAS conceived in SharCo to SMEs. The SharCo molecular tools were continually upgraded and these improvements were transferred to SMEs as well; they enabled screening, at the seedling stage, thousands of apricot progenies in which several resistance genes where pyramided and/or sharka resistance was combined with locally adapted, high value varieties.

It was expected that the translation of MAS to SMEs filled the need for high throughput selection of PPV resistant apricot cultivars adapted for cultivation all over Europe. Such an approach contributed significantly to building efficient and durable resistance to sharka disease at the European level.

8.3.18 SOILVEG IMPROVING SOIL CONSERVATION AND RESOURCE USE IN ORGANIC CROPPING SYSTEMS FOR VEGETABLE PRODUCTION THROUGH INTRODUCTION AND MANAGEMENT OF AGRO-ECOLOGICAL SERVICE CROPS. PROJECT, 2015-2018 (EU-CORE ORGANIC PLUS, ERA-NET)

This project aims at investigating the use of the roller crimping technology for the management of Agro-ecological Service Crops (ASC) in organic vegetable production. The hypotheses tested are if ASC termination by roller crimper will i) maintain yield of the cash crops and vegetable products quality, ii) reduce soil disturbance and enhance soil quality, improving internal system use of nutritive elements, iii) reduce fossil fuel energy consumption, iv) create a suppressive environment for pests, diseases and

weeds. The project will also test the hypothesis that, compared with the incorporation of ASC into the soil as green manure, the use of the roller crimper reduces nutrient losses from the soil/plant system and GHG soil emission. The project also wants to verify if the introduction and the proper management of warm season ASC in the milder climatic areas (i.e. Southern Europe regions) could be a feasible option for resilient vegetable cropping system design and management. The main expected result is the optimisation and the spreading of novel ASC management strategies aimed to improve soil quality and to enhance resources use. The Soilveg project involves 14 partners from 9 different Core Organic Plus countries.

In addition to integrated EU-projects, fruit and vegetable researchers have been very active in collaborative networks (Endure) but also in COST actions. Some of them gave birth to new integrated European projects:

8.3.19 ENDURE (2007-2010)

The Fruit community has also been active in ENDURE network. Its objectives were to define research priorities on pest control and reduction at the European level, to gather knowledge, facilities and human resources according to the needs of agricultural extension, industry, and the non-profit sector and become a source of reference satisfying farmer needs and societal expectations.

One of the output of ENDURE's network has been the creation of the EU-project **PURE**. It is a recently started EU project (2011) on the development of more and better crop protection techniques. The results of Pure will contribute to implementation of the national action plans that European countries have to draw up in the context of the EU Directive on Sustainable Pesticide Use. In four years, Pure should lead to accepted and sustainable solutions for farmers and growers in controlling pests and diseases in crops such as wheat, maize, field and greenhouse vegetables, and fruit.

8.3.20 EU-BERRY (THE SUSTAINABLE IMPROVEMENT OF EUROPEAN BERRY PRODUCTION, QUALITY AND NUTRITIONAL VALUE IN A CHANGING ENVIRONMENT: STRAWBERRIES, CURRANTS, BLACKBERRIES, BLUEBERRIES AND RASPBERRIES) 2011-2014.

To provide the necessary knowledge and tools to facilitate development of high quality, consumer-desirable fresh berry fruits of high nutritional quality optimal for human health at a competitive cost. The further objective is the development and validation of a set of tools to improve competitiveness of European berry production and consumer accessibility to berry fruits. The EUBerry platform will be developed and validated by using strawberry and raspberry and blueberry as model crop species. Additionally, specific critical points related to improvement of berry fruit quality and reduction of production costs will be considered also for currants and blackberries.

8.3.21 ROOTOPOWER (EMPOWERING ROOT-TARGETED STRATEGIES TO MINIMIZE ABIOTIC STRESS IMPACTS ON HORTICULTURAL CROPS) (2012-2015)

The EU ROOTOPOWER project (2012-2015- grant number 289365) aims to develop new tools, targeted to the root system, to enhance agronomical stability and sustainability of dicotyledonous crops under multiple and combined stress conditions. Central to our approach is the use of tomato as a model species since it can be very easily grafted, (and indeed is usually grafted in commercial protected cropping). This surgical technique attaches genetically different shoot and root systems, allowing precise assessment of the effect of altering root traits on crop performance independently of shoot traits, since the scion (shoot) is constant. This project will analyse and exploit the natural genetic variability existing in wild-relative tomato species (used as rootstocks) and their beneficial interactions with natural soil microorganisms (arbuscular mycorrhizal fungi, AMF and plant growth promoting rhizobacteria, PGPR). This project will obtain genetic information and physiological understanding of mechanisms vital for high-performing root

systems. The key research challenges are to (i) identify stress-resistant root systems and rhizosphere microorganisms (and their synergisms) for enhanced resistance to individual and combined abiotic stresses (ii) understand the underlying genetic and physiological mechanisms, which are potentially fundamental to all crops, and readily exploited in dicotyledonous crops. This project will conduct detailed analysis of the underlying rootstock-derived physiological and morphological mechanisms that influence fruit yield and quality, with special emphasis of rootstock effects on root-to-shoot signalling.

8.3.22 **BIOCOMES (2013-2017)**

This project wants to develop 11 new biological control agents (BCAs) for key markets in European agriculture and forestry. BCAs identified through market analysis and are primarily thought for use in open field vegetable crops (3), in protected crops (2), arable crops (3), fruit crops (3) and in three different forest types (2). Primary targeted pests are: gypsy moth (*Lymantria dispar*), pine weevil (*Hylobius abietis*), tomato pinworm (Tuta absoluta), white flies, aphids of fruit tree crops and *Mamestra brassicae*. Primary targeted pathogens are: damping-off diseases in forest nurseries, soil borne pathogens of oilseed rape and cereals, brown rot (*Monilinia* spp.) of stone fruit and powdery mildew of cereals (*Blumeria graminis*). The economic sustainability will be assessed; the environmental sustainability will be quantified for each BCA. The in-vitro production of entomopathogenic viruses will be developed as an innovative technology aimed at a breakthrough in economic production. All 11 BCA solutions will constitute novel IPM tools and new alternatives to replace the major pesticide applications in European agriculture and forestry.

8.3.23 **EUROLEGUME (2014-2017)**

Long term S&T objective: The project is aimed to sustainable use of Leguminous plants and soil resources in order to ensure European citizens with balanced and safe food, ensuring the high quality protein sources in their daily diet by increasing competitiveness and cultivation of legumes for food and feed. Short-term S&T objectives: 1. Evaluation of pea, fava bean and cowpea/black-eye-bean local genetic resources for the development of new varieties for food and feed and further use in breeding; 2. Development of new food and feed products from available European varieties of pea, fava bean and cowpea; 3. Selection of appropriate rhizobium strains and arbuscular mycorrhizae fungi to support nitrogen fixation and development of new, commercial inoculants; 4.Evaluation of influence of leguminous plants on the soil properties in sustainable, regionally specific cropping systems.

8.3.24 **INNOVATIVE BIOPESTICIDES PRODUCTION (2015-2017)**

This project focus on the innovative production of plant and agricultural residue based biopesticides for crop protection. Our research group (Biopesticides-CSIC) provided a significant part of the Know-How of this project and we participate subcontracted by the leader, Agrocode (Spanish SME).

8.3.25 **INDUCTOME (2015-2017)**

Induction of secondary metabolites in tomato by-products for extraction and economical evaluation of the model process. Accumulation of secondary metabolites in green plant residues due to controlled stress conditions, gene expressional and metabolomic analysis, establishment of extraction method for commercial purpose and evaluation of market potential and economic feasibility.

8.3.26 **FAVORDDENONDE (2015-2018) CORE ORGANIC**

The project activity aims at studying the effects of processing with sustainable, small-scale equipment on the nutritional and sensory quality of vegetable products (tomato, sweet pepper, apple and plum) obtained with organic and conventional cultivation systems. In the first year, the content of phytochemicals in tomatoes and apples were compared. While for the fresh products no differences between organic and conventional were found, the content of phytochemicals differed for processed products and when different processing techniques were compared.

8.3.27 SWEEPER: SWEET PEPPER HARVESTING ROBOT (2015-2018)

Development of the first generation market ready sweet pepper harvesting robot.

8.3.28 TRADITOM: TRADITIONAL TOMATO VARIETIES AND CULTURAL PRACTICES: A CASE FOR AGRICULTURAL DIVERSIFICATION WITH IMPACT ON FOOD SECURITY AND HEALTH OF EUROPEAN POPULATION (2015-2018)

Characterization and valorisation of European traditional varieties.

8.3.29 EMPHASIS: EFFECTIVE MANAGEMENT OF PESTS AND HARMFUL ALIEN SPECIES - INTEGRATED SOLUTIONS (2015-2019)

EMPHASIS is a participatory research project addressing native and alien pests threats (insect pests, pathogens, weeds) for a range of both natural ecosystems and farming systems (field crops, protected crops, forestry, orchards and amenity plants). The overall goal is to ensure a European food security system and the protection of biodiversity and of ecosystems services while developing integrated mechanisms of response measures (practical solutions) to predict, to prevent and to protect agriculture and forestry systems from native and alien pest threats.

8.3.30 EUCLID: EU-CHINA LEVER FOR IPM DEMONSTRATION (2015-2019)

The overall goal of EUCLID is to contribute to secure the production of food for the increasing worldwide population while developing sustainable production approaches to be used in the European and Chinese agriculture. The choice of the crops of interest in EUCLID, i.e. fresh tomatoes, table and wine grapes, and leafy vegetables (lettuces, cabbages, etc.), is based on their economic importance for both European and Chinese fruit and vegetable production, but also for their exemplarity in representing different production systems (field + greenhouse vegetables and ligneous perennial).

8.3.31 UNIVERSAL ROBOTIC SYSTEM FOR GRAFTING OF SEEDLING (INJEROBOT) (2016-2017)

The main objective is to perform a flexible robotic system for supporting grafting of horticultural seedlings, based on the cooperative work of two industrial robots and supported by artificial vision and external mechanical devices. Finally, it desired develop on ROS for a hardware abstraction

8.3.32 FERTINNOWA (2016-2018)

In European countries, the cultivation of fertigated crops experience scarcity of water, and the intensity of cultivation poses significant risks to water quality. The main objective of the FERINNOWA thematic network is to create a meta-knowledge database on innovative technologies and practices for fertigation of horticultural crops. FERTINNOWA will also build a knowledge exchange platform to evaluate existing and novel technologies for fertigated crops and ensure wide dissemination to all stakeholders involved of the most promising technologies and best practices. A multi-actor integrated approach is used which will involve various stakeholders (researchers, growers, policy-makers, industry, environment groups, etc.) at several levels including the socio-economic and regulatory level with a special focus on the EU Water Framework Directive and Nitrate Directive. All tools, databases and other resources generated will be shared within the consortium and the stakeholders´ group and will be made available to the broader scientific community, policy-makers, the industry and the public at large. FERTINNOWA aim is to help growers to implement innovative technologies in order to optimize water and nutrient use efficiency thus reducing the environmental impact.

8.3.33 C-ROOTCONTROL (2016-2018)

The development of long-term sustainable IPM solutions allowing to reduce the problems attributed to hairy root disease through a holistic approach, in which the plant cultivation, the irrigation system (biofilm), as well as biological control organisms (BCO's) are covered.

8.3.34 AGROSMARTCOOP(2016-2018)

To create a common space for promotion, networking and interaction with structures, tools and advanced support services for SUDOE agrifood cooperatives in order to improve technological innovation, management and marketing through the promotion of knowledge, good practices and inter-cooperation.

8.3.35 PAN-EUROPEAN CLUSTERS FOR TECHNOLOGY TRANSFER AND NEW VALUE CHAINS (ACCTIVATE) (2016-2019)

ACTTiVATe aims to foster cross-sectoral innovation among SMEs from four different sectors, aerospace, agro-food, health and ICT. The project will focus its effort in setting up strategies that allow clusters to lead the engagement of SMEs in activities intended to create new services and products and therefore the generation of new value chains and emerging industries across Europe.

8.3.36 TOMGEM: A HOLISTIC MULTI-ACTOR APPROACH TOWARDS THE DESIGN OF NEW TOMATO VARIETIES AND MANAGEMENT PRACTICES TO IMPROVE YIELD AND QUALITY IN THE FACE OF CLIMATE CHANGE (2016-2020)

Designing tomato varieties able to produce yield and quality fruits at high temperature and understanding the genei molecular basis.

8.3.37 G2P-SOL (2016-2021)

G2P-SOL is a research alliance bringing together the major European and International repositories of germplasm with public and private institutions active in genomics, phenotyping and breeding in the four major Solanaceous crops: potato, tomato, pepper and eggplant. The project aims at bringing into full fruition the seeds from tens of thousands of genetic accessions of these four Solanaceous crops that are stored in "genebanks" worldwide. Understanding and utilizing this genetic diversity is key to the sustainability of agriculture in the face of changing environment and the appearance of new pests.

9 INNOVATION AND RESEARCH FOR THE EUROPEAN FRUIT AND VEGETABLE INDUSTRY CONTRIBUTING TO H2020 EUROPEAN STRATEGY

9.1 INTRODUCTION

Despite its limited acreage compared to other crops, fruit and vegetable production is one of the prevalent agricultural activities in Europe for its economic, social, environmental relevance. Being a technologically advanced sector, the fruit and vegetable chain provides employment to a large number of EU citizens, as it encompasses the production, storage, marketing, logistics, and wholesaler and retailer sectors. Its competitiveness on the global market is highly dependent on research and development activities that can lead to improved knowledge and professional proficiency of all stakeholders involved.

Horticultural products have a privileged place on the table of EU consumers for their taste and appeal. However, stimulating their consumption should receive a high priority among EU goals, since this source of food is capable of conferring important health benefits, particularly in the prevention of many so called "social diseases".

Despite a global market and competition that is met via state-of-the-art technologies throughout the chain, fruit and vegetable growing is part of the legacy of local traditions and favours the preservation of beautiful landscapes throughout Europe.

Those outlined above are but a few traits that set the fruit and vegetable sector on par with the other major food products grown in Europe, and for whose development and inclusion in the KBBE several Technology Platforms have been created, and further organized. However, this sector and its specific needs for innovation are not appropriately represented in existing Technology Platforms. Part of this resides in several specific traits that can be associated with fruit and vegetables, and are not the norm for other crops. These include:

- Horticultural products are a unique commodity, as they are being mostly traded and consumed fresh, although processing is quite extensive. Fresh fruit and vegetables are highly perishable and need high-technology logistics.
- Both fresh and processed fruit and vegetables and derived products have highly effective health components that confer antioxidant properties, weight control properties, protection from cardio vascular diseases, and from cancer. Fruit and vegetables are considered "superfoods" because of their potential in contributing towards meeting daily intake quotas of important dietary components.
- Fruit growing requires high financial commitment (initial investments, operating cycles) and under current commercial and financial conditions this puts the fruit sector in Europe under very strong competition from non-EU countries. Neglecting the sector needs for innovation and development will expose Europe to a loss in terms of economy, land preservation and culture.
- Fruit growing is knowledge based very intensive activity and one that requires high level of professional knowledge and skills to be carried out successfully. This is a positive, in that it leads to a natural need for innovation to be brought to the sector.
- Research in the fruit and vegetable sector has historically been led at national or regional (sub-national) level. Despite EUFRIN's engendering many successful international bids that have received EU funds, at the international level much is still lacking in terms of research coordination.

- The fruit and vegetable chain will benefit from better integration to appropriately exploit the technological progress and the positives that each player in the chain is able to contribute to it.
- Fruit and vegetable consumption is decreasing, as a result of many factors, including price, limited convenience and availability, lack of consistent quality, lack of innovative fruit types or fruit-derived products.

The fruit and vegetable sector is in an excellent position to help reach the goals set out in the EUROPE 2020 Strategy of a **smart**, **sustainable** and **inclusive** economy, allowing the attainment of high levels of employment, productivity and increasing social cohesion. In fact, this sector is ideally positioned to contribute in a positive manner to **societal**, **economic** and **environmental** issues that are relevant to Europe and its economy. The following sections provide more in-depth analysis of the issues where research and technological innovation may benefit the European KBBE by benefiting the fruit chain of Europe.

9.2 THE FRUIT AND VEGETABLE SECTOR CONTRIBUTION TO SOCIETY

9.2.1 OUR VISION FOR 2030

By 2030 fruit and vegetable consumption will have considerably increased, contributing significantly to Europeans' well-being and health. The increase will be brought about by a reliable supply and consumption of healthy, accessible, convenient, novel products for European **consumers**, based on fruit and vegetables.

To meet this demand, the European **fruit and vegetable production** will contribute by providing a secure, continuous supply of consumer-oriented healthy foods. This will be delivered through European interdisciplinary research, encompassing social and natural sciences. Resulting benefits will include the development of specialist expertise **throughout the supply chain**, education through knowledge exchange, wealth creation for the rural environment, the empowerment of rural areas and the preservation of the landscape.

9.2.2 GENERAL RATIONALE

The fruit and vegetable chain is quite well positioned to have an impact on compelling societal issues in Europe. Because it is an economic- and labour-intensive activity, in several European countries horticultural farms tend to be small-medium in size, and that enhances their capacity and role in preserving the landscape and maintaining local culture, traditions and products. Fruit and vegetable growing is often a driver of local economies, which provide to it skilled labour and many services: education, logistics, technologies, marketing, etc. Over the years, this role has expanded to other societal aspects. For example, regional/national cooperatives of fruit and vegetable farmers have been formed (and still exist) almost a century ago, with the initial goal of providing market access to farmers that would otherwise not have had it, but more and more recently, access to technological improvement. Today, the largest of these outfits have reached a size that allows them to be strong economic players both nationally and internationally, providing employment and economic welfare to many EU citizens.

9.2.3 HOW R&D IN THE FRUIT AND VEGETABLE SECTOR WILL DELIVER ON EU SOCIETAL ISSUES

- Elucidation of the physiological mechanisms underpinning the 'healthy attributes' of fruit and vegetables will secure, increase and exploit these beneficial attributes thereby driving an increased consumption.
- Projected increase in global urban based populations and unprecedented climate extremes emphasize the need to focus on food security and food safety. If horticultural production is moved to non EU countries due to lower production costs the EU will become dependent on importing essential foods. Relying on imported fruit and vegetables will negatively impact on the

regions and will leave the EU at risk during times of global competition for food as we will be unable to secure a supply of food for EU based consumers.

- A generation of older growers and their expertise is being lost because younger generations prefer to be urban based. This threat on rural societies requires new innovations to be delivered into the sector driving profitability and competitiveness to secure young highly skilled growers.
- Innovation and value need to be implemented throughout the EU fruit and vegetable chain, an interdisciplinary approach needs to be taken to validate the food chain, thereby increasing the trustworthiness of the food chain, and driving an increased consumption through increased consumer confidence.
- Product variability needs to be overcome to optimize both the fresh fruit and vegetable chain and efficiencies in the processing industry, thereby increasing satisfaction and reducing food wastage.
- R&D focused on delivering EU fruit and vegetable products that are aligned to consumer needs. Consumer needs must be defined through consumer-driven R&D. The EU fruit and vegetable sector must deliver a reliable, healthy, convenient and tasty product that is a superior alternative to manufactured food products.
- Increased consumer awareness on the value of seasonal, healthy and fresh food choices will underpin growth of the EU fruit and vegetable sector.
- R&D is needed that is focused on the benefit of EU horticultural industry in retaining the natural capital in Europe. Validation of the territorial value of locally grown fruit and vegetable and validation of the EU fruit and vegetable sector in eco-tourism and in protecting the environments via land stewardship will improve consumer awareness of the value of EU fruit and vegetable choices.
- R&D focused on strengthening the role and contribution of urban horticulture to secure a healthy food supply in urban environments.
- R&D focused on delivering novel fruit and vegetable based products to meet consumer needs for new foods
- R&D delivering increased productivity and efficiencies and uniformity to ensure that the EU fruit and vegetable sector can deliver competitively priced products for EU consumers and that the quality of products exceeds consumer expectations.

9.2.4 Research in the Fruit and Vegetable Chain that can address EU societal needs

Maintaining or developing the consumption of fruit and vegetables is mainly a question of offering better access to households, both psychologically (inducing a purchasing reflex) and physically (making fresh and perishable products easily available). This is an important factor, especially as the change in lifestyles and the necessary time trade-offs this entails are pushing consumers to look for more efficient supply methods. In this context, the study of the changes in trade and purchasing patterns takes on particular relevance. Consumer science resources will need to be mobilized to provide insight into the issues at stake in the distribution of fruit and vegetables, for example via consumer panels to obtain valuable information on places of purchase (POPs) of the households, POP evolution, customer profile for the various POPs, and composition of the average shopping baskets. Some organizations (e.g. Ctifl in France) are already pioneering these studies. The barometer on the perception of points of purchase will allow to measure consumer appreciation of fruit and vegetable outlets throughout the years and to shed light on consumers' motivations and their expectations as to selling methods and services to customers. After a long period of expansion of supermarkets to the detriment of traditional specialty shops, market shares seem to be stabilising. However, within each category, thorough changes are at work. Studies will be needed to analyse and interpret these phenomena. For instance, the specialised fruit and vegetable retail sector has recently seen the emergence of fresh food specialty supermarkets, a fairly successful concept. The large supermarket chains are following the trend, trying to adapt their models. Over the last few

years, they have invested heavily in convenience store formats, which seem to have gained renewed consumer interest. They are also studying selling methods that facilitate purchase (development of drive-in supermarkets and online shopping sites). And then there is the resolve of operators in the production and retail sectors to answer the wish of certain consumers to add more social awareness to their purchases of food products. This can be done by means of quality labels or warranty certificates, or by somehow rehabilitating short distribution circuits. The goodwill value of fruit and vegetables will remain intact. However, for it to fully translate into an intention to purchase, a new generation of consumers has to be attracted and retained. Thought must be given on how distribution methods can be adapted to woo those new consumers into settling into their new habits.

9.3 The Fruit and Vegetable Sector contribution to EU economy

9.3.1 Our Vision for 2030

By 2030 all the components of the European fruit and vegetable chain will have increased competitiveness by intensive use of novel, eco-innovative technologies. These will secure greater profitability by means of increased labour efficiency, improved quality and productivity, innovative products and increased consumption of fruit (products).

9.3.2 General rationale

The European fruit and vegetable sector represents one of the highest valued agricultural businesses: despite occupying only 3% of the cultivated area, it accounts for 20% of the value of the EU agricultural production. The size of the industry warrants that efforts be made to maintain its competitiveness in the face of increasing pressures from countries external to the EU, which normally reap the benefits of lower labour and production costs, coupled to the adoption of state of the art technologies that are developed elsewhere (often in Europe). The European and vegetable R&D has historically been quite advanced in most areas, providing cutting-edge advancements from genetics to pre-harvest techniques, to post-harvest management, to logistics and sales, often thanks to EU-supported Projects.

9.3.3 How R&D in the Fruit and Vegetable sector will deliver on EU economic issues

- EU fruit and vegetable producers are facing reduced economic returns, they have reduced control in the market place due to the strength of the retailers and competition from imported products. Therefore, R&D focused on implementing new technologies into the chain are needed to increase efficiencies and profitability.
- R&D focused on delivering novel cultivars with increased productivity and reduced reliance on inputs (resource and chemical) that meet consumer requirements will drive consumption and increase profitability.
- R&D focused on delivering novel cultivars that are differentiated and competitive against alternative snack/food products will increase the likelihood that consumers will choose and consume fruit and vegetables and fruit and vegetable-based products.
- Validation of the EU fruit and vegetable sector through life cycle analysis and thereafter targeted innovation to increase the sustainability of the sector will increase its competitiveness and provide increased consumer confidence in the chain.
- R&D focused on delivering full traceability throughout the fruit and vegetable sector will increase consumer confidence in the safety of fruit and vegetable and fruit and vegetable based products.
- R&D focused on consumer choices and how to align novel fruit and vegetable products to consumer segments will drive increased satisfaction and increased consumption.
- R&D delivering novel products through innovative knowledge and technologies will increase the suite of products available to consumers and drive consumption.

- R&D focused on improving systems within the fruit and vegetable chain and that deliver digital, communication and improved decision making tools through ICT and sensor based technologies will increase efficiencies and drive profitability.
- R&D focused on increasing the linkages between industries within the entire food chain will increase connectivity and will secure a common vision for the players in the chain; this will increase efficiencies and ultimately the value of the end product when it reaches the consumer.
- R&D delivering innovation throughout the fruit and vegetable chain will improve quality and reduce wastage.
- R&D on elucidating physiological approaches to efficient production systems focused on increased density and reduced variability will increase the efficiency of the systems and underpin optimization of handling produce throughout the chain thereby increasing profitability.

9.3.4 Research that can address the economic needs of the Fruit and Vegetable Chain

Controlling and reducing biological variation in fruit quality can result in increased consumer confidence in fruit consumption, as large variation in the eating and nutritional quality of sold fruit often confuses and disappoints the consumer. Reliable markers, instruments and decision support systems will be developed to measure, control and reduce biological variation in fruit quality at the point of sale, to fulfil the expectations of the European consumer relative to produce quality including, but not limited to, its nutritional value and contribution to human health. This will be pursued with a whole-chain, i.e. from farm to fork, approach to determining the control of biological variation. Genomics, Transcriptomics and Metabolomics will be employed to gain insight into the relations between genetic, growing and postharvest practices and the variations in fruit quality. The project will provide knowledge relative to, and control of, the determinants of variation in fruit quality, affording European stakeholders a competitive advantage in the world fruit markets. The reduction of variability in fruit quality will benefit the European consumers, providing them with healthy fruit of better, more consistent quality. Allied research will focus on the development and implementation of 'omics' technologies that can detect and allow to control the basic processes underpinning quality development in the product before harvest, which are known to impact the post-harvest period, and the eating quality of the fruit. Key processes in the fruit production chain, such as cultivar choice, regulation of fruit crop load, growth control, fruit maturity assessment at harvest and prediction of physiological disorders in storage and further along the supply chain will be considered. This knowledge will give the EU fruit sector a competitive edge for the production of stable high quality fruit.

9.4 The Fruit and Vegetable Sector contribution to EU environment

9.4.1 Our Vision for 2030

In 2030 innovative European fruit and vegetable production systems will contribute to the preservation of the environment through the adoption of an array of eco-innovative technologies which will deliver better products and reduced wastage under threats from climate change and limited natural resources. This will be achieved through energy efficient systems and innovative management tools which will optimize the use of production factors, and minimize the carbon, water, mineral nutrients, pesticides footprint of the chain while improving land-stewardship.

9.4.2 General rationale

Sustainability is an important driver for many European policies, and regulations often include sustainability aspects such as 'green' public procurement: minimizing greenhouse gas emissions, reducing wastes, minimizing energy consumption and fostering efficient use of resources. Because of the interdependencies between processes involved in growing, harvesting, storing, processing, distributing and disposing of a product, sustainability requires a life cycle analysis encompassing the whole chain. "Greener" fruit orchards and vegetable plots should incorporate the smartest, safest and most effective

cultural practices developed, without any a priori consideration of the production scheme under which they have been developed (integrated vs. organic), including the positive additions derived from implementing biotechnological knowledge. The goal is that of focusing the fruit and vegetable sector on production methods that are truly the most advanced in terms of smart, careful use of all available technologies and knowledge. This includes not only the production of fruit and vegetable and fruit- and vegetable-derived products, but of biomass as well, the evaluation of land use, the consumption of water, energy, pesticides and fertilizers.

9.4.3 How R&D in the Fruit and Vegetable sector will deliver on EU environmental issues

- R&D targeted at minimizing chemical residues, increasing the use of biological pest control and the use of novel and alternative technologies to chemical regulation of fruit trees and vegetable plants will reduce the impact of the sector on the environment.
- R&D focused on delivering novel cultivars with increased pest and disease resistance will reduce the use of chemicals throughout the fruit and vegetable chain.
- R&D focused on delivering improved monitoring and forecasting through the use of smart technologies will minimize the use of chemicals and maximize the efficiency of chemicals.
- R&D delivering precision growing techniques, including real time cultural management for easy, reliable, accurate assessment of vital crop statistics, real time adjustment of production factors and precise use of water and fertilizer, and adoption of cultural practices capable of reducing resource inputs will improve the balance between the production system and the environmental resources.
- Innovative solutions for delivering in-the-field assessment of storage potential for reliable and longer storability will reduce fruit and vegetable loss during the chain.
- Innovative technologies to produce more with less; to increase implementation of sensors, artificial intelligence, intelligent management systems and remote sensing technologies will minimize the EU fruit and vegetable sector footprint.
- R&D to underpin the delivery of fruit and vegetable and fruit- and vegetable-based products with enhanced functional health properties via innovative production practices; including photo-selective films to enhance the production of pigments, use of natural compounds, modification of resource input to regulate beneficial properties will provide added value.
- R&D focused on managing and responding to climate changes, through increased knowledge and detection of new and emerging pests and diseases, validation methodologies for carbon and water footprint will secure the EU fruit and vegetable industry into the future.
- R&D delivering new detection tools for climate change issues; including smart irrigation systems, improved and new warning systems, and innovative diagnostic systems will minimize the footprint.
- R&D to reduce energy inputs via reduced chemical and fertilizer applications, adoption of soil and plant management techniques to enhance the soil natural fertility, deliver technologies to enable orchards to become effective sites for sequestering carbon and providing “green shares” will enhance the natural capital of the EU.
- Reducing waste of produce at all points of the supply chain will increase efficiencies.
- Innovative “omics” approaches to control tree behaviour and implementation of “soft-technologies” will increase competitiveness.
- Introduction of “omics”-based breeding, including development of new ideotypes addressing consumer preferences, providing growers with varieties that are easier to grow and manage along the chain, while preserving superior taste attributes will secure the EU fruit and vegetable supply.

- Innovative processed fruit and vegetable and fruit- and vegetable-products tailored to consumer segments; young, elderly, overweight, diabetics etc. Nano-encapsulation of bioactive components for enhancing functional properties of fruit juices and purees; flash vacuum expansion in processing for juice and puree; membrane technology in concentrated juice production; non-thermal product preservation (high hydrostatic pressure, pulsed electric field, ozonation, ultrasonication); edible coatings to prevent browning, microbial decay and losses of bioactive components and to enhance texture and sensory properties of ready-to-eat cut fruit and vegetables; utilization of processing wastes for industrial raw materials and biogas production will increase the consumption of EU fruit and vegetables.

7.4.4 Research that can address environmental needs of Fruit and Vegetable Chain

Fruit and vegetable growing requires intensive cultivation to achieve the high quality and production levels that are needed for it to be profitable. Emerging technologies in various sectors could be brought together in order to reduce the carbon, water and nitrogen footprint, with the goal of achieving full environmental sustainability of fruit and vegetable growing.

The integration of smart production systems that reduce energy inputs via better management of production factors with the exploitation of by-products (e.g. pruning residues for biofuels; pomace as ingredient of novel functional foods) can have significant impact in “greening” the fruit and vegetable sector. Research allowing real time assessment of relevant physiological traits via affordable sensor systems will be the basis for fine-tuning management decisions (i.e. pesticide applications, irrigation, fertilization, crop load adjustment, pruning etc.) to current production needs. Field rugged, low cost sensors of plant hydration levels will automatically drive irrigation systems geared to apply the least amounts of water, that are compatible with current crop needs, in order to maximise water savings while preserving fruit and vegetable quality and yields. The development of pesticide delivery systems that integrate knowledge on spatial, environmental and tree health will allow to minimize chemical applications, thus preserving the environment, reducing residues and decreasing production costs, via savings in chemical quantities. Monitoring relevant parameters and performance of individual plants will allow to map the spatial variability existing within the orchard/field. This information will form the basis for short/medium term management decisions so that production factors (i.e. fertilizers; water; pesticides; labour) will be applied to the various map sectors in diverse amounts, responding to actual plant needs with the goal exploiting their actual production potential.

9.5 The Fruit and Vegetable Sector contribution to innovation

9.5.1 Our Vision for 2030

By 2030 barriers for innovation adoption will be overcome and this will deliver wealth for key stakeholders in the European fruit and vegetable chain. The European fruit and vegetable research and innovation network will be strengthened and will facilitate the exchange and implementation of knowledge at the regional, national and transnational level.

9.5.2 General rationale

A common strategy is needed among the sector actors for making sure that the knowledge created by the research strategy creates impact. Impact means maintaining and creating employment, contributing to consumer-demand related food quality and safety, contributing to unique landscapes, delivering novel fruit- and vegetable-based products that respond to the needs of future European societies, continued adaptation of the sustainability concept in the sector and minimizing energy consumption. Innovation will be encouraged to make sure that more of the knowledge developments reach the commercialization stage by focusing on the needs specified below.

9.5.3 How R&D in the Fruit and Vegetable sector will deliver on EU innovation issues

- Development of robust research methodologies will allow systematic and science-based bridging between consumer- and market-demand, and natural science-derived technology.
- Systematic identification of barriers will allow implementation of innovation e.g. lack of information, knowledge or skills, time constraints, costs, organizational and structural barriers, etc.
- Systematic evaluation of prevalent regulations and standards addressing the EU fruit and vegetable sector at both national and transnational levels will provide science-based advice and expertise to the relevant authorities that establish regulations.
- Developing a proof of concept from research to business accounting to meet regional requirements whilst maintaining conceptual European principles will provide a decision making tool.
- Increased integration of the fruit and vegetable sector by a systematic organization and involvement of operational groups, e.g. growers, packing houses, processing SMEs, retailers and others will allow for the creation of European bottom-up technology exchange network, connecting stakeholders and research providers.
- Assuring appropriate research and demonstration facilities e.g. experimental farms will allow for accounting of realistic agro-ecological requirements while maintaining Common Agricultural Policy (CAP).
- Promoting public-private partnerships and other funding schemes will support innovative, high-impact technologies.
- Improving access to research-oriented pilot plants will secure knowledge exchange and implementation.
- Identification of ways to reduce the overall administrative burden thereby will encourage greater participation of Small and Medium-Sized Enterprises (SMEs).

9.5.4 Research that could address innovation needs of the Fruit and Vegetable Chain

The continuous input of innovation to the fruit and vegetable chain will be of paramount importance to place and maintain the EU fruit and vegetable industry in a position of leadership on a global scale. All sectors of the chain express a continuous demand for innovation that can only be met by strong interdisciplinary research capable of a composite view of the problems and of addressing them mobilizing appropriate resources. Innovative research focusing on the genetic basis underpinning plant and fruit attributes will focus on genomic studies elucidating the role of each gene in controlling traits and responses to the environment, which will open the way to the breeding and selection of new varieties better suited to consumer demands, to environmental constraints and with improved health attributes. Pre-harvest research will focus on innovative production systems based on newly developed sensors that will gather physiological and environmental knowledge, information on plant health and nutritional status, and will feed them to artificial intelligence systems that will minimize resource inputs while preserving fruit quality. The pre-harvest history of the crop, as well as its ripening stage and quality at harvest will be used as inputs for decision-making tools that will allow the optimization of the storage and marketing strategies based on the actual fruit and vegetable features. Processed fruit and vegetables and fruit- and vegetable-derived products are expected to become more important, as “time-poor” consumers demand more practical, portable products, for out of home consumption, ready-to-eat products, etc. Research in the process innovation will lead to significant improvements in the quality of the products obtained, and also to the utilization of by-products as novel ingredients of innovative products. Knowledge on the traits of produce and produce-derived products that are important for health benefits will be the stepping stone to guide varietal and management innovation, so that fruit and vegetables can be produced with the highest amounts of these components. This will help placing even more fruit, vegetables and fruit- and vegetable-derived products at a prominent spot in the prevention of

social diseases, such as CVD and some forms of cancer. Knowledge arising from consumer studies, providing information on consumer preferences and expectations will be essential to orient the research in the technical sectors of the chain.