Brussels, 24 March 2020

COST 013/20

DECISION

Subject: **Memorandum of Understanding for the implementation of the COST Action "Plasma applications for smart and sustainable agriculture" (PIAgri) CA19110**

The COST Member Countries and/or the COST Cooperating State will find attached the Memorandum of Understanding for the COST Action Plasma applications for smart and sustainable agriculture approved by the Committee of Senior Officials through written procedure on 24 March 2020.

Funded by the Horizon 2020 Framework Programme of the European Union

MEMORANDUM OF UNDERSTANDING

For the implementation of a COST Action designated as

COST Action CA19110
PLASMA APPLICATIONS FOR SMART AND SUSTAINABLE AGRICULTURE (PlAgri)

The COST Member Countries and/or the COST Cooperating State, accepting the present Memorandum of Understanding (MoU) wish to undertake joint activities of mutual interest and declare their common intention to participate in the COST Action (the Action), referred to above and described in the Technical Annex of this MoU.

The Action will be carried out in accordance with the set of COST Implementation Rules approved by the Committee of Senior Officials (CSO), or any new document amending or replacing them:

a. "Rules for Participation in and Implementation of COST Activities" (COST 132/14 REV2);
b. "COST Action Proposal Submission, Evaluation, Selection and Approval" (COST 133/14 REV);
c. "COST Action Management, Monitoring and Final Assessment" (COST 134/14 REV2);
d. "COST International Cooperation and Specific Organisations Participation" (COST 135/14 REV).

The main aim and objective of the Action is to investigate the potential of non-thermal/cold plasmas as a green alternative to conventional fertilizers in agriculture and to reduce the need for pesticides. The Action will also explore the use of plasmas for treatments of food and its packaging. This will be achieved through the specific objectives detailed in the Technical Annex.

The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 88 million in 2019.

The MoU will enter into force once at least seven (7) COST Member Countries and/or COST Cooperating State have accepted it, and the corresponding Management Committee Members have been appointed, as described in the CSO Decision COST 134/14 REV2.

The COST Action will start from the date of the first Management Committee meeting and shall be implemented for a period of four (4) years, unless an extension is approved by the CSO following the procedure described in the CSO Decision COST 134/14 REV2.

OVERVIEW

Summary

A continuous increase in demand for food caused by population growth represents a serious challenge for the humankind. Even in regions where food is plentiful, safety of the food cycle is increasingly important. Improving sustainability of agriculture and at the same time reducing adverse effects of agriculture on the environment requires efficient technologies that enhance productivity while maintaining food quality and safety. The main aim of this COST Action is to investigate the potential of low temperature plasmas (cold plasmas), as a green alternative to conventional chemicals in agriculture to improve yields, increase size and robustness of plants and to reduce (or eliminate) the need for antifungal agents. It will aim to break the classical field boundaries for new dimension in sustainable agriculture with lower chemical impact. The Action will address the use of plasmas for treating food and packaging. Action aims at combining efforts of numerous European scientific communities dealing with plasma, biology, agriculture and food processing with a goal of identifying and developing applications in the chain of food production. Transfer of plasma technology to industry will be based on understanding of plasma's most important processes with further considerations including (Novel food) legislations, energy consumption, food safety and quality. The Action will help define a new field in science by a coordinated, joint effort across the Europe and broader, through exchange and a better use of resources and by intensive study of the basic mechanisms within the context of the well thought out present or future applications.

Areas of Expertise Relevant for the Action	**Keywords**
● Physical Sciences: Atomic, molecular and chemical physics ● Agriculture, Forestry, and Fisheries: Agriculture related to crop production, soil biology and cultivation, applied plant biology, crop protection ● Other engineering and technologies: Food science and technology ● Agriculture, Forestry, and Fisheries: Sustainable Agriculture ● Chemical engineering: Green chemistry	● Low temperature plasma (diagnostics, modeling) ● Low temperature plasma treatments-seeds, plants and food ● Smart and sustainable agriculture ● Agricultural wastewater decontamination ● Guidelines for implementation (agriculture/food)

Specific Objectives

To achieve the main objective described in this MoU, the following specific objectives shall be accomplished:

<u>Research Coordination</u>

● Analysis of the existing problems associated with seeds (germination percentage, rate, uniformity, and seed-borne infections), plants (fertilization, watering etc.) and food products (decontamination, packaging etc.) - creation of a database of possible cold plasma assisted solutions.

● Development and characterization (modelling, diagnostics) of cold plasma sources for cost-effective direct or indirect (through plasma activated water, PAW) treatment of seeds, fruits, foods and plants in general – identification and optimisation of the most promising plasma sources.

● Detailed investigation of the interaction of plasma created species (in gaseous and liquid phase) with seed/plant cells – identification of the main mechanisms involved in plasma-cell interactions.

● Investigation of environmentally friendly cold plasma solutions for water treatment (production of PAW), manure treatment for fertilization, and purification of wastewater contaminated by pollutants originated from agricultural practices or animal farms – Toxicity and ecotoxicity tests of the stable products obtained after plasma treatment.

● Definition of procedures and protocols for specific optimised cold plasma technologies used in treatments of seeds, creation of PAW, removal of pollutants and application in food technology with attention to legislation, energy consumption, cost-effectiveness, food safety and quality aspects – in collaboration with industry and legislative bodies.

● Development of strategies for the technology transfer for medium and large scale use/application.

Capacity Building

● Establish a multidisciplinary research network in order to provide a breakthrough in understanding of mechanisms of plasma-cell interaction leading to environmentally friendly technological solutions to problems in agriculture and food industry.

● Creating and sharing new knowledge with the emphasis on testing the results and procedures at several sites, sharing of the existing facilities and resources, including human resources.

● Creation of a multidisciplinary network that will increase the potential of finding partners both in academia and industry, therefore improving inclusiveness and interaction with future users across Europe, i.e. companies, farmers, etc..

● The Action will take a special care to promote scientific development of Early Career Investigators (ECIs) and give them an opportunity to work with leading experts in various fields.

● Support and encourage activity and involvement of female researchers, both in terms of scientific and technical contribution and in supporting their roles as leaders of Working Groups (WGs).

TECHNICAL ANNEX

1 S&T EXCELLENCE

1.1 SOUNDNESS OF THE CHALLENGE

1.1.1 DESCRIPTION OF THE STATE-OF-THE-ART

Non-equilibrium low temperature plasmas (LTPs) form a very reactive environment and thus open a possibility for treatments of various types of materials due to the fact that they are environmentally friendly and, in most cases, cost efficient solutions that can supplement or replace other technologies [1-3]. The list of the effects on the targeted materials is extensive including modification of roughness, hydrophobicity, deposition of coatings, polymerization, nanostructuring, creation of active surface area on textiles to absorb dyes, microcapsules, bactericidal compounds etc.. The knowledge obtained in material processing was easily transferred into development of new plasma systems, especially those operating at atmospheric pressure, which are used in biomedical applications of plasmas [4-8]. In addition, it is well known that plasmas may be used to initiate the gas phase chemical processes leading to a number of chemically active products whose properties and identity may be well controlled by varying plasma parameters. In the field of plasma medicine [1, 9-12] special emphasis was given to the chemistry of Reactive oxygen and nitrogen species (RONS) which are of key importance in biomedical applications.

First studies pointed out that plasma created RONS observed in treatments of seeds and plants led to successful, but scarce, application of plasmas for different aspects of agriculture and food industry [13-17]. Under standard conditions, antioxidant systems of the cells minimize the perturbations caused by RONS. Plasma created RONS temporarily and locally add to the level of oxidative stress, but under certain conditions these added RONS may result in positive effects. It was shown that, both low pressure and atmospheric pressure plasmas can be successfully used in stimulation of the seed growth, increase of germination percentage and decontamination, breaking of dormancy or lengthening of the seed sprout. Plasma treatment of seeds became one of the starting points in opening of a wide area of applications of plasmas in agriculture and related biotechnologies. In direct plasma treatments, i.e. where seeds are in direct contact with plasma or its afterglow, the surface of seeds undergoes a variety of changes. Depending on the plasma conditions the surface is activated so other functional groups can be attached (-COOH, -COH, -COO, $-NH_2$, -OH, -NO etc.) and at the same time seed surface can be etched and/or decontaminated from various types of microbes.

Lately, as an alternative to the direct plasma treatment of seeds and plants, Plasma Activated Water (PAW) achieved similar results in the increase of germination, decontamination of both seeds and plants and faster growth. At the same time, application of PAW allows a much simpler, wider and more cost effective implementation of the plasma treatment.

The reason for these enhancements is because, in comparison to regular water, PAW contains significant amounts of chemically active species produced in plasma and at the plasma-liquid interface. These species are transferred from the interface volume to the liquid bulk and are able to trigger desired responses in biological samples. Some of the most important species appearing in the liquid bulk of PAW that are involved in triggering cell mechanisms are OH, O, NO, H, H_2O_2, NO_2^-, O_2^-, NO_3^-, OH^- [18, 19]. The same set of species are known to be efficient in destruction of organic pollutants. For years the use of atmospheric pressure plasma sources has been investigated for biological or chemical decontamination of air, water and soil as an alternative to classical pollution control techniques. High removal efficiency of a large variety of water contaminants (including phenolic compounds, organic dyes, pharmaceuticals, pesticides, etc.) has been achieved without requiring addition of other chemicals, as in other advanced oxidation processes [19, 20]. In standard agricultural practices, organic contaminants (e.g. pesticides) are used and they usually end up in various bodies of water. Some of these chemicals are characterized by high stability and are resistant to environmental degradation, they are highly toxic and may bio-accumulate, with potentially significant impacts on wildlife and human health. While plasma treatment proved effective in removing many of the pollutants, it is still a challenge to provide a common type of plasma system or procedure that can be used in all cases and for all types of pollutants. In addition, the mechanisms responsible for degradation of these pollutants under plasma conditions still require investigation, their elucidation representing a key step towards the optimisation of the plasma technique for water treatment. One needs to add that further research is required to understand the products of plasma treatment and to provide assurance that those would not be harmful.

Previously described plasma capability as an antimicrobial agent has been explored for sanitation of food products. Indeed, the emergence of new pathogens contaminating the food and changes of production technologies and of consumer's lifestyle and requirements, climate change and mass production are posing new and peculiar challenges. As an example, the raising consumption of fresh produce and raw food has been associated to a growing number of outbreaks of food-borne illnesses [21]. In this framework, non-equilibrium plasmas present several possibilities of high-interest. First is the promise of a non-thermal process capable of disinfecting different foods (and also food processing equipment) from various microorganisms, with limited or only superficial impact on food characteristics [22]. Additional positive features are that plasma is a dry technology and that the produced antimicrobial agents, reactive species and UV radiation, are created locally and are not associated with harmful residues [23]. These characteristics have spurred many research projects on food sanitation using both low pressure and atmospheric pressure non-equilibrium plasmas. Plasma disinfection potential has been demonstrated against several food-borne pathogens (e.g. *Aspergillus niger, Salmonella typhimurium, Listeria monocytogenes*) and for a variety of different foods, such as rice, egg shells, spices, fruits and fresh produce [23, 24]. One of the strong advantages is that so far no resistance of pathogens to plasma treatments has been found and confirmed.
Until now the research on direct plasma or plasma assisted applications in agriculture was performed in different laboratories, with various types of plasma sources and with different types of seeds, plants and foods. Regardless of the positive results obtained until this moment, the collaborations between two or three laboratories are not sufficient to deal with the challenges of this field. The 2017 Plasma Roadmap identifies the field of applications of low temperature plasmas in agriculture and food industry as one of the major challenges [1]. The problems underlined as the most essential at the moment are identification of mechanisms, verification of plasma efficiency, development and improvement of plasma devices and definition of functional and cost effective approaches to implementation in agriculture and food industry.

1.1.2 DESCRIPTION OF THE CHALLENGE (MAIN AIM)

The continuous increase in demand for food caused by population growth represents a serious challenge for humankind. The United Nations Food and Agriculture Organization (FAO) estimates that around 11 % of world population is suffering from chronic undernourishment and that this percentage is on the rise. At the same time, the climate change is having significant impact on agricultural production and farmers are forced to adapt or change existing practices due to the change in weather patterns, pest appearance, water availability etc. Changes in resource availability and their prices will inevitably lead to disbalance in global food production. As an example, one of the largest industries, animal feed industry, takes up to 33 % of the total arable land with of 8 % of the global human water consumption (source FAO). In 2005 this industry used 6.3 billion tons of feed biomass with emissions of about 3.2 Gt CO_2.eq (source FAO). As the most important source in obtaining animal protein for human food it faces many challenges with the global warming influence, new policies set to meet carbon emission and other sustainability requirements. However, farming activities are not the only factor contributing to the total amount greenhouse gas (GHG) emissions related to food production. Industry of synthetic fertilizers contributes with global average emission of 8.45 kg CO_2.eq/kg product and pesticide industry of 25.5 kg CO_2.eq/kg crop from production and transport (source FAO). At the same time, one of the goals of the Sustained Development Goals (SDG) initiative defined for the period 2015-2030 is "***End hunger, achieve food security and improve nutrition, and promote sustainable agriculture***". Even in regions where food is plentiful, the safety of the food cycle is increasingly important. Along with the goals of the World Health Organization (WHO) 2025, SDGs 2030 require increased investment in nutrition improvement through research, wider implementation of new programs and policies with greater commitments on global and national levels. Improving sustainability of agriculture and, at the same time, reducing adverse effects of agriculture on the environment requires efficient technologies that enhance productivity while maintaining food quality and safety. ***The idea for the COST Action "Plasma applications for smart and sustainable agriculture (PlAgri)" stemmed from the need to address some of these challenges and help achieving the SDGs 2030 through scientific research of multidisciplinary teams and creation of new and innovative technological solutions with the strategies for their broad implementation.***
At some extent plasma technology is already present in the agricultural industry through treatment of livestock manure for production of fertilizers with favourable CO_2-footprint as compared to the conventional industry solutions using gas or coal. Nevertheless, more challenges lie ahead in both technology improvement and meeting of the demands of regulatory bodies and end-users. This is only for one segment of the huge and complex field.
Obtaining high yields in agricultural production starts with planting seeds that rapidly germinate in high percentages, after minimal delay while producing robust plants. Therefore chemical treatment of

seeds is widely used for both protection of seeds against pathogens and pests, and for stimulation of germination and fertilization. ***The main aim of this COST Action is to investigate the potential of non-thermal plasmas as a green alternative to conventional fertilizers in agriculture to improve yields, increase size and robustness of plants and to reduce (or eliminate) the need for pesticides. The Action will also address the use of plasmas for treatments of final products – treatments of food and its packaging.***

Realizing that plasma application is a promising method for treatment of human cells, cancer cells, decontamination of bacteria and viruses, the plasma community turned to the equally important issue of applying plasma in the agricultural sciences. This interdisciplinary field of plasma physics and botany, though rapidly growing, is in its early stages when fundamental issues are still being investigated [1, 13-16], but, on the other hand, it has matured enough to produce several applications with industrial or wide scale potential. In the last several years, researchers have investigated the use LTPs for treatment of seeds in order to improve germination uniformity, yield and rate, and to reduce contamination by fungi and bacteria. The results are extremely promising, clearly showing the potential of the method and that LTPs can be a very efficient tool in the processing of seeds. However the investigations were conducted on very different systems, under a wide range of conditions and using quite different protocols, making comparisons and consequently systematic progress in the field difficult. These isolated, but successful experiments have framed important and fundamental questions that must be addressed to make progress in the field:

1. What are the fundamental mechanisms responsible for the positive effects of low temperature plasmas on seed germination and plant growth?
2. How can plasmas be used to protect seeds from fungi, viruses and bacteria without harming the seed (or in concert with stimulation of seeds)?
3. Are there unique properties of varieties of seeds/plants that may produce different responses to the same set of plasma parameters?
4. Evaluation of the competitiveness of plasma technologies against other technologies, new or established?
5. Can these similarities and differences in response to plasma parameters be used to define standard procedures and protocols that can be broadly implemented in agriculture?
6. Are the quality and safety characteristics of plasma treated foods meeting the required standards?

The scientific field of plasma agriculture would therefore greatly benefit from leveraging the insights and abilities of researchers addressing the fundamental issues of the cross-section of two fields: physical plasmas and biological systems. As one of its goals, the COST Action (PlAgri) will have to address these fundamental issues, both scientifically and in the form of producing new technological solutions and protocols.

In order to obtain the answers to the questions raised by the community the PlAgri Action will investigate these fundamental and technological issues by addressing the following challenges:

- Developing models and using extensive diagnostics to characterize LTP systems used for applications in agriculture and for treatments of food, and the interaction of LTPs with seeds, plants, and foods.
- Defining and fundamental understanding of the mechanisms underlying the positive effects obtained by direct or indirect (through plasma-activated water) LTPs treatments of seeds, plants and food products.
- Identifying economic and environmental benefits and drawbacks of the LTP technologies in comparison with established technologies (chemical fertilizers, pesticides, etc.)
- Quantifying the fundamental mechanisms of plasma treatment of agricultural wastewater, manure and of plant growth media (solid/liquid) that will be reused in agricultural production.
- Understanding the use of plasmas in treating food with the goal of laying the foundation for the transition of the technology to the industrial scale, while taking into account safety, quality, economic and regulatory considerations.
- Proposing standard protocols and procedures in plasma assisted processing of seeds, plants, water and food for a wide range of users.
- Choosing appropriate laboratory prototypes of LTP systems that can lead to applications in households and greenhouses and giving guidelines for scaling up of these systems for use on farms and in industry.

The development of models, construction and detailed characterization of LTP systems will be the first big challenge that needs to be overcome in achieving the Action goals. The investigated LTPs will be used in direct and indirect treatment (through PAW) of seeds and plants and one of the main goals in the PlAgri Action will be to reach the optimisation of LTPs parameters used in treatments. The application of PAW is also closely related to rapidly developing field of plasmas interacting with liquids

[18, 19]. Researchers have shown that PAW rich in RONS can be used as a fertilizer on soil or directly on plants [14, 17]. In this regard, the Action challenge is to investigate the fundamental properties of PAW interactions with seeds and plants, and propose standard protocols and procedures for the use of PAW aiming to speed up and increase plant growth resulting in better yields, while protecting plants from bacteria, fungus and animal pests. Success in PAW treatment of plants has the potential of greatly reducing the use of conventional chemicals which often end up in water systems as harmful and hazardous contaminants. In related research, plasmas have been shown to be a potentially effective method to decontaminate water, leaving no harmful or lasting remedy. A striking possibility of the use of PAW in agriculture is merging the processes of water decontamination with the production of PAW – production of plasma fertilizer from recycled water.

Achieving scientific and technological challenges in the application of LTPs in treatment of seeds and plants will improve community's fundamental understanding of mechanisms of plasma-plant cell interactions responsible for the positive effects of plasma treatment (and, therefore, answering the fundamental questions raised by this Action). At the same time, the technological aspects of the Action challenges will be to create laboratory standalone prototypes of the optimised LTPs and offer them to the industrial and private sector to choose promising plasma devices and techniques in order to use them for further development and large scale implementation. The PlAgri Action aims to define new procedures and protocols that will help the end user to successfully implement the LTPs systems and also to give guidelines for scaling up such systems.

Finally, another area of interest is the use of LTPs for food processing. Motivated by the antimicrobial properties of plasmas, several studies have started exploring the use of LTPs for the sanitation of food products and extending their shelf life. These investigations are addressing the needs of industry for innovative sanitation technologies, capable of disinfecting different pathogens without modifying the characteristics of the processed foods. The ideal characteristics of these methods would be dry technologies having a potential for disinfecting food, packaging and processing equipment from different types of microorganisms. In this regard, LTPs are being studied for modifying packaging (enhancement of barrier properties, production of smart packaging), allergen control in foods and processing environments, meat curing [25] and as an accelerated oxidation technology for the analysis of food oils and oil-containing food products [26]. Despite the high interest in LTPs for food processing, many fundamental issues are still unanswered. For example, the quality and safety characteristics of plasma treated foods have not yet been extensively explored. In this regard the Action aims at combining the efforts of the European scientific communities dealing with plasma and food processing with a common goal of identifying applications in the food chain where plasma technology could have the potential for translation to the industrial scale. These investigations will be performed while considering legislature, energy consumption, cost-effectiveness, food safety and quality aspects. Furthermore, plasma technologies under investigation will be compared with the competing technologies, both established and innovative ones, to assess plasma strengths and weaknesses.

1.2 PROGRESS BEYOND THE STATE-OF-THE-ART

1.2.1 APPROACH TO THE CHALLENGE AND PROGRESS BEYOND THE STATE-OF-THE-ART

The conventional technologies used in protection of seeds before planting, during the germination period and after, when plant is developing, involve usage of different kinds of chemicals, fertilizers and pesticides being the most common. Regardless of the positive results gained from the use of these chemicals there are some negative aspects that also need to be taken into account. One of them is consideration of production processes that involve chemical by-products that are not environmentally friendly. Another important issue arising in recent years is an increase in the supply/demand imbalance (FAO data) of the most common fertilizers (especially nitrogen). Also, the usage of pesticides brings problems like contamination of the water, extinction of sensitive species (bees as the most important example), contamination of final food products etc. all resulting in detecting traces of pesticides in human body. All abovementioned, together with the defined SDG 2030, is demanding new innovative approaches like low temperature plasma technology to tackle some of these issues.

The positive effects of plasma treatment of seeds, plants and foods are already known to a certain extent as described in Subsection 1.1.1. Innovativeness in this approach lies in the fact that plasma technology is a green technology that is not producing harmful chemical by-products. In case of seed treatments, for example, it is improving the germination percentages and rates and at the same time plasma treatment is decontaminating the seed before sowing. Regardless of the type of treatment (direct or indirect by using PAW) the effects are similar, but optimal application of each type of plasma demands a different set of plasma parameters. Not to mention that the type of seeds, plants or food

used in the experiments will also result in a different optimal sets of parameters. PlAgri Action aims to unify this knowledge and experience in order to define standard protocols and procedures for treatment of seeds, plants and foods. It is important to identify the treatment parameters that are crucial for obtaining the desired effects and also the points when further application of plasma becomes detrimental. In order to finish this major challenge detailed models have to be developed and extensive diagnostics of plasma systems needs to be done. In parallel, plasma chemistry needs to be determined as well as detailed biological response of plasma treated seeds and plants.
These results of the multidisciplinary research done in the PlAgri Action will lead to the optimisation of parameters for most promising LTP devices (protocols for the treatment procedures will be defined). At the same time the guidelines for the large scale systems will be defined for the interested industrial parties in order to start process of implementation of the developed plasma systems into large scale farming or food industry.
In the domain of the fundamental research, on the scale of individual cells, researchers involved in PlAgri aim to identify and characterise mechanisms responsible for the positive plasma effects. The work that needs to be done can be divided in several aspects: (i) effects and mechanisms involving cell membrane and cell wall; (ii) effects and mechanisms involving intracellular structure and signals; (iii) the timeline of the plasma impact-during the treatment and after the plasma exposure. This will lead to the improved concepts and understanding of plasma-cell interactions.
The knowledge on mechanisms involved in the plasma interactions with liquids will also be used to improve the efficiency of destruction of organic pollutants originated from agricultural practices. As in case of treatments of seeds and plants, the network will aspire to develop the most efficient plasma sources that can be applicable by a broad range of users. Along with the new technological solutions in form of the most promising prototypes, PlAgri aims to define the protocols and procedures together with the safety measures and make it available to the different communities.
Furthermore, food processing is associated with a set of specific challenges to be dealt with regarding the safety (e.g. induced allergenicity, toxicological profile) and quality aspects of plasma treated foods. Much is at stake here, since some characteristics such as nutrient content, colour, aroma, texture and chemical composition were altered, plasma technology may reduce the overall quality of the products. A very important consideration will also be to comply with the Novel Food Regulation. In addition scale-up prospects, and the cost-effectiveness are required for the application on the industrial scale. Significant efforts will be dedicated within the Action to investigate these cornerstone aspects of food processing.
A highly multidisciplinary community is required to achieve the goals set by this proposal. This means that plasma community (physicists and chemists), together with colleagues from agriculture, life sciences and food industry, need to work in coherence. This approach across disciplines will create a new dimension in this interdisciplinary research field.

1.2.2 OBJECTIVES

1.2.2.1 Research Coordination Objectives

The primary goal of PlAgri is to create a world leading multidisciplinary network which will combine physicists, engineers, agricultural scientists, food technologists, biologists and chemists with an aim to study the influence of the cold plasma treatments of seeds, plants and food products. This platform will lead European research community in the direction of developing a new discipline of plasma applications in agriculture and food technology and also to numerous future applications.
The Action will achieve this goal by pursuing the following set of objectives:

- Analysis of the existing problems associated with seeds (germination percentage, rate, uniformity and seed-borne infections), plants (fertilization, watering etc.) and food products (decontamination, packaging etc.) – **database of possible cold plasma assisted solutions.**
- Development and characterization (modelling, diagnostics) of cold plasma sources for cost-effective direct or indirect (through PAW) treatment of seeds, fruit and plants in general – **identification and optimisation of the most promising plasma sources.**
- Detailed investigation of the interaction of plasma created species (gaseous and liquid phase) with plant cells – **defining of the main mechanisms involved in plasma-cell interactions.**
- Investigation of environmentally friendly cold plasma solutions for water treatment (production of PAW), manure treatment for fertilization and purification of wastewater contaminated by pollutants originated from agricultural practices or animal farms – **performing toxicity and ecotoxicity tests of the stable products obtained after plasma treatment.**
- **Definition of procedures and protocols for specific optimised cold plasma technologies** used in treatments of seeds, creation of PAW, removal of pollutants and application in food

technology with attention to legislation, energy consumption, cost-effectiveness, food safety and quality aspects – in synergy with industry and legislative bodies targeting a common user.
- **Development of strategies for the technology transfer for medium and large scale use/application.**

Strategic Objectives of the Action will be:
- to achieve high level of research broadly distributed across Europe and in cooperation with centres from outside Europe that would provide a platform for further development towards industrial applications;
- to take advantage of the leading position of European scientists and convert it into applications and advantage for European industries (agriculture, food industry and other);
- to facilitate exchange of scientists (especially ECIs) to even the level of education and skills, targeting ITCs, and to take better advantage of the existing facilities;
- to aid science based development of industrial research and practice with a goal of sustained development and reduced cost to the environment, energy reserves and general quality of life;
- to work towards development of more focused and specific proposals within small subgroups and in cooperation with the industry.

The fulfilment of the objectives will be complemented by comprehensive dissemination of the research results to all relevant stakeholders in order to maximise both short and long impact of the Action.

1.2.2.2 Capacity-building Objectives

The list of objectives given in Subsection 1.2.1 will be achieved by using the current expertise and research capacities of the stakeholders involved in the Action and by creating and sharing new knowledge obtained during the Action's life. Important aspect of the work would be testing of results and procedures at several sites, sharing of the existing facilities and resources including human resources. Due to the type of the objectives, the Action will fully support and take advantage of the COST initiative for multidisciplinary research. PlAgri will provide a breakthrough, both in scientific and technological sense, in understanding of mechanisms of plasma-cell interaction and giving technological, environmentally friendly solutions to the problems in agriculture and food industry.
The Action will take a special care to promote scientific development of Early Career Investigators (ECIs) and give them an opportunity to work with leading experts in various fields. During the course of the COST Action all stakeholders will actively seek the other research funding opportunities as a capacity-building objective. The existence of PlAgri will help in making it easier to find partners both in academia and industry, therefore improve inclusiveness and interaction with future users, i.e. companies, farmers, etc. across Europe. The Action will fully support and encourage activity and involvement of female researchers, both in terms of scientific and technical contribution and in supporting their roles as leaders of Working Groups (WGs).

2 NETWORKING EXCELLENCE

2.1 ADDED VALUE OF NETWORKING IN S&T EXCELLENCE

2.1.1 ADDED VALUE IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

The objectives of the PlAgri Action coincide with the H2020 framework programme effort to create more environmentally friendly technological solutions that will tackle the challenges brought by Earth overpopulation, shortage of food and contamination of waters. In the field of applications of plasmas in agriculture and food new conferences and workshops are being organized in the last few years with the topics that include objectives covered by PlAgri. The PlAgri Action covers within its scope research topics that are currently of great interest to several scientific communities making it a highly interdisciplinary project. These topics contribute to the development of new emerging field of applications of plasmas in agriculture and bring new interdisciplinary dimension of knowledge in the field of plasma application in food industry.
A few European projects have already targeted the application of non-thermal plasmas for food processing: non-thermal sterilization (SHEALTHY), pulsed electric field food processing (i3-food),meat (MEAT PACK), milk (Emilk), eggs (EggSterilisation), fresh produce (SAFE-BAG) and fruits (Cleanfruit). These results were promising, but limited in scope and cover only a small part of the present Action. No European projects dealing with treatments of seeds, growing plants or agricultural water were accepted/submitted until now at the European level. Current research is very broken and

separate communities do not communicate efficiently with each other in a broad field. At the moment few personal contacts exist, but it is necessary to connect interested parties all across Europe (and world) in order to get the research in plasma agriculture field to higher and more effective level. Europe will be recognised as a world leader in this field which tackles whole humankind through successful networking of the PlAgri Action.
At the moment, there is no existing interdisciplinary research network that is addressing the same objectives as defined within the PlAgri project. Supporting PlAgri activities would bring together a wide, interdisciplinary research community from plasma physics, agriculture, food, biology and chemistry with the aim to form world leading interdisciplinary cloud with high knowledge in currently diverse fields. The joining of the interdisciplinary forces at this level is only possible through COST association. This will give the PlAgri Action the opportunity during its term to offer the new technological solutions in the form of devices and procedures. At the same time, the fundamental science will benefit greatly through the joined investigation of plasma-cell interaction mechanisms led by physicists and biologists at the EU (world) level. In the food industry the Action will offer new solutions in treatments of food and packaging, all crosschecked with the latest Novel Food Regulation.

2.2 ADDED VALUE OF NETWORKING IN IMPACT

2.2.1 SECURING THE CRITICAL MASS AND EXPERTISE

The PlAgri network includes more than 22 COST Country Institutions (63.6% Inclusiveness Target Countries), 1 Near Neighbour Country Institutions (NNCs), 3 COST International Partners (IPCs) and 1 European RTD Organisation. The number of the included research teams across the world reflects the high interest for the objectives dealt by PlAgri. The excellence of the proposers in their respective research fields will guarantee a long-lasting impact of the Action results on the field of plasmas in agriculture and food industry. The proposers have authored a significant numbers of scientific papers, books, technical solutions and patents, attended large number of renowned conferences and presented their work. Besides collaboration within academia, proposers have long lasting collaboration with industry partners which will be used to promote PlAgri results to the companies. Partners from NNC and IPCs will also actively support Action by providing valuable scientific contributions.

2.2.2 INVOLVEMENT OF STAKEHOLDERS

The most relevant stakeholders in PlAgri COST Action can be divided in several groups.

- ***The interdisciplinary scientific community***: Universities and research institutes working on the topics that are the primary focus of the PlAgri Action. One of the main tasks of the Action will be to involve more researchers working in the field of plasma physics, plant biology, molecular biology, chemistry, agriculture (crop farming) and food technology. This will be done through organization of Workshops (WSs) and Special Conferences session where world leading specialists will be introduced to the new field of plasma agriculture. At the Universities the Action will aim to involve both postgraduate and undergraduate students through scientific and popular lectures presenting the research topics of the Action. Research community will be also attracted though giving the possibility of the Short Term Scientific Missions for the ECIs in the Action topics.
- ***The industrial community:*** The Action will aim to involve industrial partners from the relevant industries like food industry (food and packaging), agricultural and chemical (seed production, crop growth, fertilizers, pest control, etc.) and pharmaceutical (medicinal plant growth). The initial network of the industrial partners will be widened through specialized seminars and presentation of the concepts and technical solutions organized for the partners. Effort will be made during the Action to present the PlAgri and its achievements in the relevant industrial fairs in order to introduce the potential stakeholders with the objectives of PlAgri Action.
- ***The local private sector:*** The Action plans to involve as much as possible the stakeholders that include farmers, local organic food producers, garden hobbyists and, in the case of food processing, the final consumers. This will be done mainly on the local level thorough the activity of the Action proposers. The popular lectures will be organized and local media will be involved so that the local community is acquainted with the potential technical solutions, concepts and prototypes offered by the Action.
- ***The regulatory and public bodies:*** The Action will aim to have close collaboration with policy makers in order to be able to improve and adapt the plasma assisted solutions for future easier implementation. This interaction needs to be two-way with exchange of knowledge and with introducing the legislators with the potentials of the new emerging green technology in agricultural and food industry.

The Action during the four year span will proactively involve new stakeholders by using dissemination plans described in Section 3.2.2 and WG2. The networking tools made available by the COST system will be used throughout the community in order to achieve a joint effort, better distribution of ideas, facilities and resources and better coherence of the Action of an otherwise a very complex and interdisciplinary topic.

2.2.3 MUTUAL BENEFITS OF THE INVOLVEMENT OF SECONDARY PROPOSERS FROM NEAR NEIGHBOUR OR INTERNATIONAL PARTNER COUNTRIES OR INTERNATIONAL ORGANISATIONS

The proposal will benefit from the involvement of the researchers from the 1 NNCs (Belarus) as well as 3 IPCs (USA, Japan and Canada). In case of NNCs the benefits for those countries are the significantly improved possibilities to exchange knowledge with the colleagues from the COST countries. On the other hand the researchers from the COST countries will have the opportunity to widen the number of partners from the agricultural industries of NNCs. The involvement of the non-EU countries, especially if on different continents with different climates (Canada, Japan etc.), brings to the Action scope types of plants and food groups specific for those cultures and climates. All three IPCs have large funding allocated in the developing field of the plasmas in agriculture and the industries interested in research topics covered by PlAgri Action so the benefits will be a significantly widened network of stakeholders.

3 IMPACT

3.1 IMPACT TO SCIENCE, SOCIETY AND COMPETITIVENESS, AND POTENTIAL FOR INNOVATION/BREAK-THROUGHS

3.1.1 SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS (INCLUDING POTENTIAL INNOVATIONS AND/OR BREAKTHROUGHS)

Ambitious objectives of the Action coincide with the challenges defined in the H2020 framework programme and the SDG 2030. Researchers, institutions and projects included in the network will be committed to successfully reach the goals defined through milestones and deliverables of the project by exploiting the main characteristic for the COST approach - the encouragement of a strong collaboration throughout the scientific community and industrial partners across disciplines. The short term scientific impacts of the Action, such as the understanding of the optimal plasma chemistry and mechanisms of plasma-cell interactions, collaborations of many multidisciplinary teams and boost in the number of published papers in the Action's topics will lead to a long term impact of the formation and development of the new scientific discipline of Plasma Agriculture. Also, the understanding of these fundamental processes can have significant impact in other related fields of plasma-bio applications that are still within or just outside the scope of the project (medicine, stomatology etc.). Development and scaling of the plasma devices will lead to the improvement of the existing and design of new power supply systems and other measurement and monitoring equipment. The long-term socioeconomic impacts can be manifold. At the moment plasma technology is increasing its presence in the huge market of livestock farming through treatment of manure for fertilizer applications. The idea is to reduce (or eliminate) fossil-based nitrogen fertilizer by fertilizer created from plasma treated manure and to reduce the annual costs for chemical fertilizer from ~30-40k euro to zero. The carbon footprint is also one of the important factors when long term socioeconomic impact of application of plasma technologies is concerned. The preliminary studies show reduction of 30% per kg of milk in dairy farms with plasma treatment of manure. Similarly, in removal of volatile organic compounds plasma technology (0.4 kg CO_2.eq) has 7 times lower global warming potential than Wet Flue Gas Desulphurization with Selective Catalytic Reduction (3 kg CO_2.eq) or biofiltration (0.9 kg CO_2.eq). The companies that are pioneering the agricultural industry with plasma technology are in need of network that can be created through COST approach in order to pick up the promising technologies and applications for further development. And vice-versa, the Action needs to attract as many as possible green technology companies that will provide guidance for improving plasma systems and legislation bodies that will help with the public acceptance and regulatives incorporating plasma technologies in the food chain.

3.2 MEASURES TO MAXIMISE IMPACT

3.2.1 KNOWLEDGE CREATION, TRANSFER OF KNOWLEDGE AND CAREER DEVELOPMENT

The PlAgri Action aims to create knowledge databases on the main problems in the processing and planting of seeds, plant cultivation, decontamination and re-usage of agricultural wastewater, food processing and packaging with the emphasis on the possible solutions that can be achieved by using LTP systems (see D3.1-D6.1). Detailed modelling and diagnostics of LTPs identified as potential systems, as well as investigation of treatment effects and understanding of mechanisms will result in publication of scientific papers in high-quality scientific journals. The COST members will present the achievements at the renowned conferences in form of the invited lectures and oral presentations. Apart from active participation in the conference programs, PlAgri will organize special sessions (half day/one day sessions) dedicated to the applications of LTPs in agriculture. During the course of the Action specialized workshops and two training schools will be organized (see table in section 4.1.2). The training schools will have the special task to transfer the knowledge to the PhD students and ECIs though specialized lectures on the PlAgri topics. These specialized workshops and training schools along with the STSMs will help the further development of their careers in the interdisciplinary field of plasmas in agriculture. Even more important will be knowledge transfer between academia and companies interested in application of plasma technology. Special sessions during workshops/conferences will be dedicated to presentation of potential, characteristics and efficiency of plasma technologies to industrial partners, legislative and public body representatives. These meetings will be aimed as a two-way knowledge exchange, where academia will need to learn what should be improved in order to develop more efficient plasma technologies that can be incorporated in the real life applications. At the same time industry, public and legislative bodies need to become aware that some of the existing rules need to be changed in order to allow plasma technologies into the food chain. With this and with STSMs that will be conducted with the industrial partners new career choices as liaisons can be opened at both sides.

3.2.2 PLAN FOR DISSEMINATION AND/OR EXPLOITATION AND DIALOGUE WITH THE GENERAL PUBLIC OR POLICY

The PlAgri Action will have a detailed dissemination plan which will be revised and updated on yearly bases. A separate Work Group (WG2 in the work plan) will be dedicated to dissemination and communication of the Action’s plans and results. The necessity to form a separate WG for these tasks lies in the fact that even if there is good communication between academia members there should be significant improvement in communications with industry, policy makers, public bodies and end-users. It is necessary to coordinate knowledge and services needed by the industry and end-users (small farmers, horticulturists, greenhouses etc.) with the services available in the research community. The standard ways of dissemination will be readily available and updated regularly during the course of the Action. This includes, but not limited to:

Action website – The portal for the members of the Action and other interested parties to obtain information about the Action itself (objectives, goals and organization), ongoing activities, future plans and scientific and technological achievements (public area). It will provide Master and PhD students, post-docs and possibly future group leaders looking for career opportunities with the necessary information on other laboratories or companies. The Action website will also have internal database (member only area) for the participants containing STSMs reports with obtained data, internal WGs reports, etc.

Social networks – The Action will be visible on social platforms such as Facebook, Twitter, Research Gate or LinkedIn.

Internal reports – Members of the Action will be encouraged to prepare internal scientific and technical reports describing the achieved progress. Reports will serve as a basis for discussions at the WG meetings in order to shape drafts for joint journal and conference papers or to prepare documents for the protection of intellectual property.

Publications – One of the results of the Action’s activities will be joint publications in high-quality scientific as well as popular scientific journals. Some of the journals being - Scientific Reports, Plasma Sources Science and Technology, Plasma Processes and Polymers, New Journal of Physics, Plant Physiology, Journal of Agriculture and Food Chemistry, Journal of Agronomy and Crop Science, Water Research, Journal of Food Processing and Preservation, etc..

Annual report – Annual reports will be presented at the Action’s website. They will contain scientific advancements, major results and technical breakthroughs produced by the WGs.

Action book – The last report will be published as the Action book. It will give a summary of the Action with highlights of the most important scientific and technological breakthroughs achieved in the four year span. The book will be prepared by the WG leaders, Action Chair and Vice Chair serving as editors. The final report will serve as the basis for preparation of a review article.

Special attention will be given to the organization of:
Workshops – Workshops (WS) will be held on yearly basis with mandatory contributions from all the WGs on their scientific and technological development. The WS will be an open event and invitation will be sent to the researchers and partners from the industry and private sector. Proceedings of each WS will be published at the Action website.
Training schools – due to the interdisciplinary nature of the Action training schools will be organized for the members of the Action (especially ECIs). The experts from all scientific fields will give short tutorials and training lectures in order to transfer knowledge between the researchers and different scientific fields.
Conference half/one day special sessions – Special sessions will be organized as an addition (separate entity before or after) to the most eminent conferences in all related scientific fields involved in the Action. This will give the members of the Action opportunities to acquaint wider audiences with the objectives and results achieved by the Action.
Interaction with industry and policy makers – attached to workshop/training school/MC meeting there will be organized special sessions where policy makers, industry representatives and potential end-users will be invited to give the overview of the current needs and problems and to discuss the possibilities of the application of plasma assisted solutions (See T2.6).
The plan will be adjusted taking into account the evolution of the Action itself (through new achievements and ideas, research progress) and joining of the new countries. The stakeholders will ensure that the plan of dissemination is followed in detail during and after the Action period.

4 IMPLEMENTATION

4.1 COHERENCE AND EFFECTIVENESS OF THE WORK PLAN

4.1.1 DESCRIPTION OF WORKING GROUPS, TASKS AND ACTIVITIES

The Action will consist of five working groups:
WG1. Dissemination and communication
WG1 will aim at the effective dissemination and outreach of the Action results. **The main objectives will be: (•) to ensure effective communication between all partners within and outside of WGs, (•) to coordinate the dissemination and outreach activities, (•) to create interest and raise awareness among the relevant stakeholders and policy makers on the outcomes of the project.**
T1.1. Gathering material for PlAgri Action website and launch of the website
T1.2. Development of promotional and informational materials. Flyers, annual e-newsletters containing the WG2-WG5 results for the attention of the public at large;
T1.3. Launch of the Action's social media presence (Facebook and Twitter). All partners, in collaboration with their respective public relations/communication departments, will disseminate outcomes in public talks, TV talks, podcasts or articles in newspapers;
T1.4. Contact and communication flow with existing and potential partners; Involving of relevant policy makers and industry representatives for better science-industry interaction through organisation of special sessions at workshops or conferences;
T1.5. Organization of the Workshops and Training schools; Organisation of conference half day/one day sessions to acquaint wider Academia audiences with the Action objectives;
T.1.6. *Organisation of half day/one day sessions for general public and small farmers; Organisation of special sessions with industry representatives and policy makers; – joint discussions about the existing issues and regulatives, the presentation of available plasma assisted solutions; discussions about improvements of the available plasma assisted technologies and of existing regulations and helping to shape a new ones*
WG2. Low temperature plasma treatment of SEEDS
WG2 will focus on seed treatments using cold low- and atmospheric-pressure gas plasmas as well as plasma-activated water (PAW). **The main aim of WG2 is twofold: (1) to advance the current understanding of the physical and biochemical changes induced by plasma treatments of seeds; and (2) to develop guidelines and protocols that can be adopted by the rapidly growing community working on plasma treatment of seeds.** The tasks of this WG are multidisciplinary and will be equally distributed between physicists and seed biologists. WG2 will be using the results and conclusions obtained from WG4 on plasma treatment of water and feedback to WG4 on their effect on seeds.
T2.1 Plasma treatment (active plasma/afterglow/PAW) of seed for improved germination uniformity, percentage and rate

- Study of germination (percentage, uniformity, rate) of treated seeds; where and how plasma may affect the dormancy release
- Investigation of biomechanical and surface changes in treated seeds (endospore weakening, surface roughness and functionalization, surface energy and wettability, etc.); Characterization of physiological and biomolecular changes induced in treated seeds
- Optimization of plasma sources and operational parameters; Determination of safe exposure levels of various seed groups to plasma assisted treatments
- Comparison of plasma treatments with classical treatments: efficacy, cost and ecological footprint
- Development of guidelines, protocols and procedures for plasma treatment of specific seed groups

T2.2. Early growth characteristics and induced resistance of plants grown from plasma treated seeds

- Effects of the plasma treatment of seeds on the number of leaves, root branching, biomass production, photosynthesis capacity etc. measured during the plant development
- Determination of pathogen resistance in plants grown from plasma treated seeds
- Investigation of the effects of the environmental conditions on plants grown from plasma treated seeds (agricultural factors like drought and floods, light, etc. will be investigated)
- Will be performed in close relation to Task 2.1. when developing protocols and procedures for treatment of seeds

T2.3. Decontamination of seeds

- Investigation of plasma assisted removal of seed-borne pathogens (fungi, spores, bacteria and viruses); Toxicity study of decontamination treatments
- Optimization of plasma sources and operational parameters for seed decontamination
- Development of guidelines, protocols and procedures for plasma decontamination of specific seed groups. Comparison with recommendations from T2.1. and T2.2

T2.4. Construction, diagnostics, modelling and scaling of plasma systems for treatment of seeds

- Small scale laboratory prototypes will be developed to carry out T2.1-2.3 and enable reactors to be transported between different locations as needed (e.g. between labs at different institutions, to green houses, to industrial partners, etc.)
- Development of plasma diagnostics and models to aid advancements in tasks T2.1-2.3
- Life Cycle Assessment (LCA) will be performed; Safety and scaling up guidelines will be developed based on the knowledge gained in previous subtasks T2.1.-2.3.

WG3 Low temperature plasma treatment of PLANTS

In WG3 the network will be working on tasks involved with cold plasma treatments of plants. As with seeds, active plasmas and afterglows will be used for direct applications on plant tissue. PAW will be used for treatments of both plants and soil. **The goal is to define standard protocols and procedures for usage of plasma and/or PAW aiming to speed up and increase plant growth and development resulting in better yields.**

T3.1. Treatment of plants by PAW

PAW, liquid or in aerosol form, will be used for fertilization of plants through leaves and/or soil and decontamination potential of PAW applied to the plants will be investigated

Physiological responses in plants after treatments by PAW will be investigated; studies of toxicity of the applied PAW on plants (enzyme, DNA, proteins, chlorophyll content etc.)

Duration - persistence of PAW treatments on plants will be investigated together with the withdrawal period if some unwanted side effects are discovered

Obtained results and knowledge will be compared to the results obtained through classical methods and compounds that are already in use; Combination of plasma assisted treatment together with classical compounds will be investigated

Procedures and protocols to standardize treatments will be developed

T3.2. Direct treatment of plants by using active plasma and afterglow

Plasma will used for decontamination and fertilization through leaves as an environment chemically rich with RONS- results will be compared to the results of classical treatments;

T3.3. Development of plasma systems optimized for the treatments of plants

Construction, diagnostics and modelling of active and afterglow plasma systems will be performed in close relation to the Tasks 3.1.-3.2.

Where possible, laboratory, testing prototypes will be further developed to small and portable devices that can find use in households and small green houses: Detailed instructions and protocols will be defined as well as LCA will be performed

WG4 Plasma treatment of agricultural wastewater, growth media, manure and production of PAW

WG4 will be devoted to the following: **(1) developing procedures for efficient decontamination of wastewater of agricultural origin and for treatment of growth media (solid/liquid) and manure;**

(2) creating protocols for productions of PAW (Plasma Activated Water) that will be mainly defined by the type of application of PAW. The work of the community in WG4 will be firmly cross-linked with the activities in all other WGs.

T4.1. Wastewater treatments and decontamination of water by atmospheric pressure LTPs

Water treatment processes based on non-thermal plasma combined with classical treatments (e.g. biological) will be developed for purification of wastewater contaminated with pollutants originated from agricultural practices or animal farms (pesticides, antibiotics, bacteria etc.)

PAW characterization of chemical and physical properties. Toxicity and ecotoxicity tests of the stable products that remain after plasma treatment

Developed procedures for plasma treatments will be compared to classical water treatment practices and, if successful, classical procedures will be complemented by plasma treatment

T4.2. Plasma treatment of water for creation of PAW

Atmospheric pressure LTPs will be used for treatment of unpolluted water in order to obtain PAW; Optimization procedures for treatments of water will be developed

Detailed chemical and physical characterization of PAW will be performed (HPLC, LC-MS, UV-Vis, etc.) with a special care given to the tests for determining a possible toxicity of PAW

Aging effect on the PAW characteristics will be investigated and accordingly procedures for storing PAW will be determined and recommended for end users

This task will be performed in close relation to the tasks T2.1, T2.3. and T3.1

T4.3. Plasma assisted treatment of the plant growth media (soil, water) and manure/organic waste

LTP treatment of the plant growth media and manure for the fertilization purposes

Chemical and physical characteristics with emphasis bactericidal and fungicidal characteristics of the treated growth media will be determined; Possible toxic effects will be investigated;

T4.4. Modelling and development of plasma systems for treatments of growth media

Characterization of plasma systems specifically constructed for wastewater treatment, growth media treatment and production of PAW: detailed diagnostics and modelling will be performed

Where possible well characterized (LCA included) laboratory systems which show the best potential in applications will be turned in prototypes ready to be used by common users

WG5 - Applications of plasma processes and technologies in food industry

WG5 will focus on exploring the potential of LTP technologies in food processing and preservation, with the final aim of ensuring safer food and of increasing the shelf life, reducing wastes while preserving the food quality. **The main aim of WG5 is: identification of the applications in the food production chain where plasma technology could have a potential application transferable to the industrial processing environment. WG5 will aim to develop plasma sources and technologies with attention to legislative, energy consumption, cost-effectiveness, food safety and quality aspects.** The use of plasma treated water as an antimicrobial agent in WG5 will be based on the results and conclusions from WG4 on plasma treatment of water and, at the same time a feedback to WG3 will be provided.

T5.1. Identification of key food applications and plasma technologies with a potential for their transfer to the production while also considering the Novel Food legislation and consumer acceptance aspects

Definition of a technical roadmap for research in plasma processing for the food chain; this roadmap will result from a round table involving experts from various facets of the field and from a profound analysis of the current state of the art.

Identification of key food applications with the potential for being transferred to the production environment (e.g. food sanitation, food stabilization, sanitation of food processing environment, packaging sanitation and modification, allergen control in foods and processing environments)

For each application, identification of key parameters to evaluate process efficacy

For each application, evaluation of the most promising plasma technologies (e.g. direct or liquid mediated plasma treatments) to be investigated, their risks, potential pitfalls and competitive non-plasma technologies

Definition of key parameters and their acceptable levels to assess food safety and quality after plasma treatment

T5.2. Functional characterization of key food applications

Definition of standard operating procedures to be adopted by the groups working on each process in order to obtain comparable results across various laboratories

For each application, process efficacy will be evaluated against the key parameters identified in T5.1

Electrical characterization of the plasma devices to support the analysis of the energy expenses of the treatments

For direct treatments, identification of the main chemical species and quantitative analysis of key plasma parameters (e.g. concentration of specific chemical species, UV radiation, electronic density and temperature). For the case of treatments mediated by plasma activated liquids, similar information will be obtained from WG4

Identification of the physical-chemical mechanisms which enable key food applications

Task 5.3. Analysis of food safety and quality

Detailed characterization, benchmarking the safety and quality of the treated foods (e.g. physical properties, organoleptic properties, vitamins content, chlorophyll content, bioactive compounds content, antioxidant activities, enzymatic activities, endogenous enzymes, enzymatic browning)

Shelf life analysis, along with food quality tests during the shelf life

Task 5.4. Intermediate scale up of selected technologies and processes

The most promising applications will be selected and then plasma devices will be up-scaled to an intermediate level (e.g. pilot plants)

Life Cycle assessment (LCA) and studies of related tools (such as carbon or water footprints) will be performed as an essential element on the evaluation of the environmental performance of plasma technology in the food value chains. Therefore, LCA will be applied in order to guarantee that environmental impacts are also considered during scaling up of plasma and that transfer of burdens among stages of the value chains does not occur.

4.1.2 DESCRIPTION OF DELIVERABLES AND TIMEFRAME

Dissemination and Communications Deliverables				
No	Title	Description	WG	M.
D1.1	PlAgri visual identity and website	Setting up of the Action website; Social media presence	1	3
D1.2	Yearly WS proceedings: Y1-4	Contribution by all WGs to the WS proceedings	1	12, 24, 36,46
D1.3	PlAgri publications	Contributions of all WGs publications (journals, conference proceedings etc.) during the PlAgri duration	1-5	4-48
D1.4	PlAgri Action Book	Publication of the PlAgri Action book – overview of the Action Final status; contribution of WGs in the form of Final reports	1-5	48
Scientific Deliverables				
No	**Title**	**Description**	**WG**	**M.**
D2.1	Report on existing problems in seed processing and proposing of plasma assisted solutions	Identification of major problems related to germination and infections in different groups of seeds; creation of internal report containing types of seeds of interest, problems, classical methods used for solving them; LTPs as potential solutions	2	12
D2.2	LTP systems used in seed treatment based on their efficiency - protocols and procedures	Characterisation, modelling and optimization of LTPs; physiological and biochemical characterisation of treated seeds; development of protocols and procedures for treatment of seeds depending on the seed type and desired effects	2	30
D2.3	Plasma laboratory prototypes for seed treatment - safety protocols/scaling-up	Defining and reporting on safety protocols for specific seed treatments and guidelines for scaling up of proposed systems	2	46
D3.1	Identification of the main issues in plant cultivation – WG report	Identification of plants of interest; Internal report: types of plants, level of interest for a wider community (medicine, cosmetics, horticulture etc.), problems in their cultivation, classical solutions, potential plasma systems for problem solving	3	10
D3.2	Set of the most promising plasma systems in plant treatment	Detailed diagnostics and modelling of plasma systems; Investigation of physiological responses of plants to plasma treatments; Optimisation of parameters	3	30
D3.3	Protocols for small scale LTP laboratory prototypes	Defining the protocols and procedures for common user that must be followed during applications on plants; Reporting on guidelines for scaling up	3	46
D4.1	LTPs in treatment of wastewater, growth	Applications of atmospheric pressure plasma sources in treatment of wastewater, growth media	4	10

	media and PAW production- WG report	and PAW production;		
D4.2	Characterisation and optimisation of LTP applications: production of PAW, wastewater, growth media	Internal report on the characteristics of the most efficient plasma sources, optimisation-modelling and diagnostics; Toxicity tests of treated media used for application with plants or re-usage for irrigation;	4	30
D4.3	Development of laboratory prototypes – water and growth media	Development of prototypes of most efficient plasma systems for decontaminating of water, production of PAW and treatment of growth media; Guideline for scaling up of the systems	4	46
D5.1	WG5 Technical roadmap - key food applications and standardized procedures	Identification of key food applications and requirements they pose on plasma technologies; definition of standardized procedures to be adopted across the laboratories (also taking into account the legislative aspects)	5	11
D5.2	Functional characterization of the identified key food applications	Report on 1) the process efficacy of the identified key food applications and 2) the chemical-physical characterization of the employed plasma devices	5	23
D5.3	Identification of the fundamental mechanisms and evaluation of safety/quality aspects	Report on 1) physical-chemical mechanisms, 2) food safety/quality aspects and 3) life cycle assessment associated to the investigated key food applications	5	35

Based on the activities and deliverables of each WG, the following Milestones of Action can be presented:

Milestone	Description	M.
MS1	Action start: Kick-off meeting and election of WG Chair and Vice-Chair	0
MS2	Annual Workshops: Year 1-4	12,24,36,46
MS3	MC/CGA meetings: Year 1-4	12,24,36,46
MS4	CGA committee meeting-report on current status	26
MS5	Training schools: TS1-TS3	12,30,46
MS6	Half day/one day sessions: SpS1-SpS3	12,30,46
MS7	Action book	48

4.1.3 RISK ANALYSIS AND CONTINGENCY PLANS

The risks of the Action are formidable and should not be easily neglected since they stem from the fact that this is fully interdisciplinary project and success of the project is directly connected to the strength of the stakeholder network.

Management Risks:

Lack of involvement of WGs Chair/Vice-Chair and low interaction within WGs

Contingency: Solving the problem with the corresponding WG Chair/Vice-Chair. If this does not lead to a solution, MC and CGA Committee will nominate a new WG Chair. At the same time, if some of the WGs shows lack of interaction available COST tools will be used to tackle the problem e.g. reserve more STSM for the problematic WG.

Lack of or insufficient dissemination efforts

Contingency: Dissemination efforts will be closely monitored by the MC Chair/Vice Chair and CGA. At Action's yearly meetings detailed dissemination plan for next year will be prepared and discussed. The researchers involved in the Action have outstanding publishing track record, they are regularly giving invited lectures at renowned conferences and their collaborations ensure spreading of the scientific ideas and results.

Scientific/technical Risks:

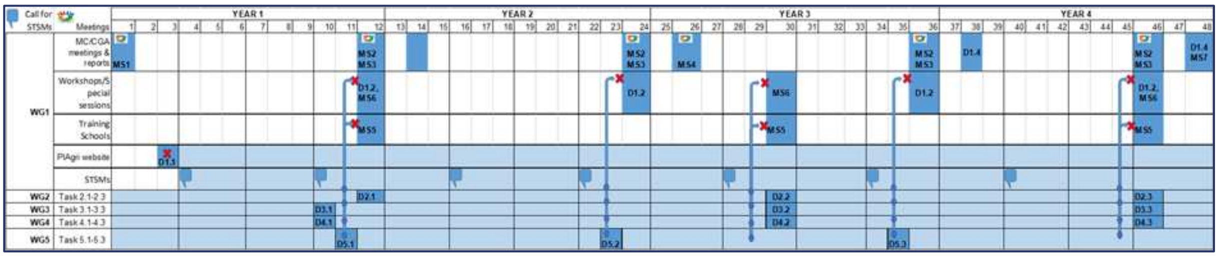
Insufficient financial support of members from national foundations and other sources

Contingency: The members of the WGs will be from different countries which minimize the effect of insufficient research funding in one specific country. Due to the organisation of WGs and Tasks within the Action, the activities of the researchers will not be limited to only single WG. Involvement through PlAgri will also raise possibilities for joint proposals in H2020 framework.

High complexity of the Action aims

Contingency: To prevent or solve this risk close collaboration between the research members of the Action needs to be established. The results need to be evaluated on regular bases in order to detect the problem in earliest stage and to start working on the solution.
Disinterest of the potential industrial partners and local producers in PlAgri technological solutions
Contingency: It is important that the potential end-users are involved from the beginning and step by step in the development of the specific technology or method so they could be acquainted with the processes from the early stages. If there is synergy between the usage of classical methods and processes with LTPs it should be emphasized.

4.1.4 GANTT DIAGRAM



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