FOODINTEGRITY

Ensuring the Integrity of the European food chain

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FINAL REPORT

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[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

Executive Summary

FoodIntegrity is a 5 year, interdisciplinary project funded under Framework 7, that aimed to assure the integrity of our food. The project comprised 60 participants from EU Member States, China and Argentina. FoodIntegrity was commissioned in 2014 against the background of general erosion of consumer trust regarding the authenticity and provenance claims of food in general and was written during the outbreak of the horsemeat scandal in 2013. The key issues identified at that time were: a clear need to link up the major stakeholders in the agri-food sector, establish sharing of intelligence, data, and best practice; provide rapid fit-for-purpose screening and verification tools; the need to fully exploit past and present work; provide a consolidated research base from which to identify and commission new work, as well as provide a source of expertise to advise on future activities within Horizon 2020, and develop more predictive and preventative measures that can provide stakeholders with an early warning of the integrity of their food being compromised.

FoodIntegrity has recently finished but its legacy remains and in many areas, will be sustained for many years to come. It is viewed by many stakeholders: DG SANTE, DGRTD, DG AGRI, Industry and consumer groups as one of the most successful EU projects in the food space. It has, over its 5year period, successfully brought together a wide range of key actors in the food chain into a common place and exposed them to the state of the art in terms of research outputs, tools and best practice. Over 1400 visitors from over 45 countries have attended the annual conferences and the related satellite events that are now routinely part of *the* primary global conference that focuses on combating food fraud. Such has been the success of the FoodIntegrity "brand" that outside partners are now keen to sustain the conferences into the foreseeable future.

A key part of FoodIntegrity is research and ensuring key gaps in the state of the art are addressed and translated into potential applications. The project has addressed key topic areas that have previously been found wanting, i.e. rapid methods, non-targeted analysis, early warning systems, consumer behaviour, non-analytical approaches, an open source information resource on methods of analysis concerned with authenticating food, and citizen science approaches to detecting food fraud. Furthermore, following detailed gap analysis, the project procured €3M of new research in the areas of: authenticating complex foods, rapid in-situ methods, transparency in the food chain and validation protocols for non-targeted analysis. The project has produced 24 peer reviewed publications to date, with many more in press, 10 videos, user friendly industry guides, infographics, 8 international newsletters that are viewed in over 40 countries, a YouTube Channel, a Network of over 300 members world-wide that can discuss food integrity issues, dissemination workshops/sessions in Europe, China, North and South America, Africa and South East Asia.

FoodIntegrity has made major contributions to policy and standards organisations and related "think tanks" concerned with food authenticity. Its members have contributed to discussions with: DG Agri, DG SANTE, DG MARE, DGRTD, FOOD2030, and the FoodFraudNetwork. In terms of industry it has contributed to discussions within GFSI, ILSI, FIIN, Food & Drink Europe and EuroCommerce. In terms of international standard setting its members have made significant contributions to Codex, CEN and ISO discussions on a common set of terms and conditions for food fraud.

The main impact of FoodIntegrity has been that all stakeholders are now better informed, share best practice, have better networks, better tools, improved methods and systems for addressing food fraud and for improving consumer confidence in the food they eat.

A summary description of project context and objectives

The provision of safe and authentic European food produced to defined quality standards is a key expectation of consumers as well as a key selling point for the European agri-food economy. European food is recognised globally for its high standards of production, labelling and safety. As such it is susceptible to lower quality imitations that seek to exploit the added value that European products have with respect to consumers and the global food market. Counterfeiting of food products has a major detrimental effect on the EU food industry as consumers start to doubt the authenticity of European brands. Whereas food safety within Europe is well coordinated and has a high profile, this is not the case for detection of food fraud or the enforcement of associated legislation. The main stumbling blocks to progress are reluctance to share data/intelligence/reference materials due to concerns from industry about competition, the need to protect the brand specification and the market price, lack of trust in third party understanding of the data and concerns about consumer reaction.

In recent years, consumer preferences for food with declared provenance has led to an increase in the marketing of foods from designated origins/productions and a strengthening of European legislation regarding the labelling of food. As a result, the food industry has become much more engaged in establishing an infrastructure that will assure food authenticity/provenance and is seeking to actively contribute to assuring the authenticity of the food supply. There was is a clear need for an initiative that will link up the major stakeholders, establish data sharing tools and working practices, provide rapid fit for purpose screening and verification methods, exploit past and present work and provide a consolidated research base from which to identify and commission new work, as well as provide a source of expertise to advise on future activities within Horizon 2020. The FOODINTEGRITY project has played a valuable role over the last 5 years in fulfilling that need and delivering a legacy that will help protect future generations from food fraud as well as protecting the added value of the European agri-food economy.

Rationale behind the proposal

There was a disturbing difference between the number and type of food authenticity and food fraud cases detected and reported by EU enforcement community and compared to the frequency and breadth of issues investigated by the private sector within Europe. There was a worrying information and intelligence gap in this area that is derived from insufficient information sharing between the food industry and the enforcement community leading to undetected food fraud in the European Union. This status quo had to be changed, and FoodIntegrity aimed to contribute to that task. Food authenticity and quality are linked and both can have major implications for food safety. Non-compliance with legislation can range from mistakenly mislabelled items and misdescription of quality claims to sophisticated, malicious and dangerous fraud. Systems and processes are required at the industrial level that can be applied to all areas, i.e. early and rapid detection of non-compliance and link to quality systems. Whereas food supply chain systems contain information on many parameters relating to food items there is no coherent process for integrating food authenticity data into the supply chain or for utilizing the data to assure product integrity.

There is a technology gap between the methodologies made available to industry and enforcement and those used by leading analytical food authenticity research establishments, e.g. the recent step changes in capability with respect to non-targeted analysis have yet to be implemented into enforcement or food production settings. The adulteration of food is usually driven by economic incentives and may, in some instances, be malicious. The significant food safety implications and the associated risks to public health should not be overlooked. Yet in many member states there is a significant gap in food fraud knowledge and intelligence within those agencies responsible for food safety yet some of the most acute food safety incidents arise as a result of food fraud activities. A clear and current example of this is the presence of excessive levels of methanol in illicit and counterfeit spirit drinks, which pose a significant risk to consumers. Food safety agencies need access to horizon

scanning capabilities and food fraud intelligence. The key to consumer protection is the bilateral and rapid sharing of information and intelligence about suspected and actual incidences of food fraud and adulteration between the food industry and the enforcement community, without prejudice. Partnerships between government and trade associations should facilitate information sharing and enforce laws and regulations that protect the honest producer. A 'horizon scanning' system is required for identifying emerging food fraud issues by examining correlations between commodity prices and links with levels of fraud and differences between production and traded volumes. This would be a move towards a proactive rather than reactive intelligence led system for the detection of food fraud and would be highly desirable. Whilst commodity adulterant or commodity specific analytical tests are useful, high throughput non- targeted screening methods are the key to moving towards a proactive system that assures the integrity of the food chain, adding value to the agri-food economy and ensuring the quality of the food that consumers eat. Recent opinion suggests that organised crime syndicates are increasingly behind cases of food fraud and adulteration. Consequently, expertise in this specialised area needs to be made available to the major stakeholders involved. Food fraud is constantly evolving and the priorities will inevitably change within the lifetime of this project. A central focal point with extensive capability and knowledge relating to detecting food fraud is required. Food fraud impacts on the food industry and it is essential to have industry engagement to share their expertise and intelligence to ensure the added value of European food is not eroded. It is essential to ensure the integrity of European exports in the face of concerted counterfeiting in any countries and to understand the purchasing behaviour of consumers in the face of such threats to product integrity and to exploit opportunities to develop new export markets for EU food.

Project Objectives

The aim of FoodIntegrity (FI) is to:

- provide Europe with state of the art and integrated capability for detecting fraud and assuring the integrity of the food chain;

- develop a sustainable body of expertise that can inform high level stakeholder platforms on food fraud / authenticity issues and priorities;

- act as a bridge that will link previous research activities, assess capability gaps, commission research and inform Horizon 2020 research needs.

The FoodIntegrity project will achieve these aims by fulfilling the following specific objectives

1. Establish an international network of expertise that will inform regulatory and industry stakeholders about food authenticity issues and inform Horizon 2020 on future research needs.

2. Consolidate available information on existing datasets, available methodology and establish a tangible knowledge base that can be interrogated and which will facilitate data sharing between European stakeholders.

3. Prioritise research requirements to fill the commodity, method, reference data and intelligence gaps.

4. Commission research and development needed to address the gaps.

5. Develop fit for purpose verification methods and systems for three food commodities that are significantly affected by adulteration and fraud (olive oil, spirits and seafood).

6. Investigate consumer attitudes and perceptions toward food authenticity and traceability, of European products, in home and emerging markets (using China as a case study).

7. Develop and test an early warning system for use by stakeholders that can identify potential food fraud events.

8. Provide practical tools and systems that can be integrated into food industry production and supply chains for assuring the integrity of food.

Ensure knowledge transfer of FoodIntegrity outputs and initiatives to the food industry, regulatory, enforcement, research and consumer stakeholders.

Main S&T results/foregrounds

Some of the S&T results/foregrounds of the project are summarised below:

- A FoodIntegrity network has been established comprising experts and stakeholders on food integrity issues.
- Eight scientific opinions ("white papers") on key scientific issues chosen by stakeholders have been published/submitted/in press in high profile scientific journals and summarised in end-user friendly video/infographics. Another 16 peer reviewed publications published with several more in press
- A user-friendly knowledge open source knowledgebase of information on analytical methods used for authenticity/fraud detection purposes has been produced, beta tested and its sustainability secured through agreed hosting at the new European Commission, European Food Fraud Knowledge Centre at the JRC, Geel, Belgium. It will go live in 2019.
- Comprehensive analysis of gaps in food fraud research undertaken in 2014, 2017 and 2018 the latter outputs will be transmitted to DG Research in order to inform Horizon Europe.
- Transnational study of olive oil regulations and standards around the world together with an assessment of the best methods currently available for detecting geographical origin of olive oil.
- Assessment and technology transfer of rapid methods for authenticating spirit drinks has been undertaken
- Large pan-European citizen science study of fish mis-description in the HORECA sector has been completed and revealed substantial mislabelling in the restaurant sector
- A toolbox linking seafood claims to analytical and paper trail methods has been produced
- A wiki containing news stories on food integrity issues has been developed together with a novel algorithm for collecting news stories on food integrity issues
- A study of Chinese consumers on how they perceive and purchase European food products together with guidance to European industry on how best to market their products to Chinese consumers
- A system for predicting the type of food fraud involved when a food incident occurs together with a fully functioning Early Warning System for predicting food fraud risks
- A range of methods and processes for authenticating of complex foods including a novel method using protein signatures and methodology for tracking markers of composition and stability along the food-production chain
- Use of mobile phone technology to detect species substitution in the fish sector.
- Feasibility study on information sharing and analysis along the food chain to identify emerging food integrity issues, together with the development of a practical system for improving supply chain integrity through data sharing
- The development and validation of a protocol, to process large data sets originated from untargeted analyses
- NIRS microsensors and ICT platforms for ensuring on-site authentication of high added value European foods in a real food industry production system

- Industry applications in the area of: guides and tools, assessment of rapid methods for application within industry (XRF, hyperspectral imaging, Laser induced breakdown spectroscopy, NIRS, Raman)
- Six major FoodIntegrity dissemination events: York 2014 (150 attendees), Bilbao 2015 (200), Prague (250) and Parma (350), Belfast (200) and Nantes (300)
- 17 workshops and external dedicated sessions (York (2), Bilbao (2), Prague (2), Lodi, Lisbon, Parma (2), Budapest, Belfast, South Africa, Canada, China, Singapore and Nantes) have taken place to discuss key food integrity issues.
- International outreach activities included FI support and presentations for major conferences in China, South Africa, Argentina and Canada.
- In addition, FI participants have presented and contributed to following international organisations/committees: CEN, Standing Committee for Agricultural Research, European Commission lunchtime seminar, Codex, GFSI.
- Publications to date: 8 FoodIntegrity newsletters, 50 publications to date, papers and 20 videos.
- A website which is a central source of information on all aspects of food authenticity

WP specific S&T results/foregrounds

WP1. Food Integrity Network

1) The FoodIntegrity Network has brought together producers, distributors, processors, retailers, regulators, researchers, enforcers and consumers into one space. This platform has then been used to form Expert Panels with relevant expertise in specific fraud issues, food commodities, analytical methodologies or other topics as required to develop Scientific Opinions of significance to the 'Food Integrity Global Community' and present/share them with a wider audience.

Key Outputs

1) FoodIntegrity Network Portal – The FI Network Portal, hosted on the FI Website is a searchable online platform that stakeholders and experts in the area of food authenticity can sign up to and use.

2) FoodIntegrity Expert Panels - The Expert panels were formed from the FI Network and have fed into: WP2 (Knowledge Base) to identify or help facilitate the sharing of databases of analytical data and information; WP3 (Prioritisation) to help identify what kind of analytical methods need to be developed or what data is missing to detect fraud or to protect industry added value.

3) FoodIntegrity Scientific Opinions - The expert panels (key output No 2) were also formed into authorship groups to draft and publish 8 scientific opinion papers on a range of food authenticity subjects, derived from stakeholder needs/requests. The papers have been published with "open access" in several high impact peer-reviewed food journals.

4) FoodIntegrity Videos – In order to disseminate the complex topics to a wider non-scientific audience, the information in the Scientific Opinions (key output No 3) were converted into videos and animated info-graphics and posted on various social media platforms.

5) FoodIntegrity YouTube Channel – In order to increase the dissemination of the Scientific Opinion videos and animated info-graphics (key outputs 3 and 4) a YouTube channel was created to host these and other video material covering FoodIntegrity conferences, scientific applications, consumer attitudes, industrial integration and food fraud information sharing.

6) FoodIntegrity Awareness Raising Seminars/Workshops - WP1 has supported numerous workshops and conferences around the world, providing expert speakers and helping raise awareness of food fraud and food integrity around the world, e.g. Lisbon, Lodi, Brussels, Hungary, South Africa, Argentina

WP2: Knowledge Base

The FoodIntegrity Knowledge Base is comprehensive tool for use by industry and regulatory authorities linking each food product and its potential integrity issues to appropriate analytical strategies that can be used for food fraud detection or authenticity testing. It allows to identify, easily and rapidly, potential threats to a given food product or ingredient and the existing solutions. The Knowledge Base contains information including the type of the fraudulent practice, the analytical methods available, their use, performance criteria, and links to literature or standards. It contains about 320 entries up to now. A transfer to the European Commission JRC is ongoing and will be completed in the first half of 2019.

FoodIntegrity Handbook

Written by nearly 50 experts in food authenticity, the FoodIntegrity Handbook is intended as a simple, searchable guide to food fraud / food authenticity issues and a perfect complement to the knowledgebase. Each of the food product chapters follows a similar structure. It starts with a general overview of the product, with a short introduction to the industry sector and current standards of identity or related legislation, both in the European Union and on the international level. Food authenticity and the analytical solutions available to address existing concerns are then described in detail for each food product, starting with food fraud problems that are currently facing the food industry or have occurred in the past. Follows a review of the analytical methods used to test for authenticity. In this section care has been taken to highlight those methods that are most commonly used, and in particular, those that are officially recognised.

The FoodIntegrity Handbook deals with a wider range of food products: eggs, nuts and seeds, spices, wines, spirit drinks, tea, flavourings and gelatine, in addition to the main food commodities: cereals, coffee, dairy products, fish and meat products, fruit juices, honey, oils and fats. It is accessible freely on the web, chapter by chapter or as a whole.

Standard for consistent reporting, comparison and integration of analytical data

A document has been produced that establishes a set of guidelines for the production and use of authenticity data. It includes minimum requirements for meta-data used for the interpretation of analytical results and for a good common understanding among food authenticity researchers. These guidelines comprise 3 sections:

1. General guidelines (experimental design, sampling plan, sample pre-treatment, etc.),
2. Technique specific guidelines,
3. Framework for multivariate models.

WP3 Gap analysis

Food integrity research needs were identified and prioritized by consultation of various groups of stakeholders. Some of the topics were addressed in the FoodIntegrity project, when they became the aim of one of the new work packages after the initial year of the project. Others and emerging needs led to three research themes that were identified as important areas of future food integrity research: Fraud prevention, methods and information to consumers. Each theme comprised five topics. This strategic research agenda provides funding bodies and researchers with a systematic framework to address future food integrity research. The strategic research agenda was presented in the future

requirements session at the 5th FoodIntegrity conference in Nantes (2018) and will be forwarded to DGRTD to inform Horizon Europe.

1) Report: Food Integrity gap identification leading to procurement – the initial gap analysis

Between March 2014 and December 2014, research gaps were identified and prioritised to guide the procurement of new research sub-projects as part of the Food Integrity project. Identified research gaps were collated, with the ten most frequently mentioned gaps subsequently being prioritised by a group of expert stakeholders at a workshop in Brussels that featured a range of stakeholders, e.g. DG AGRI, SANTE, RTD, Nestle. The prioritisation resulted in a list of four gaps which were reformulated into broad topics and were further demarcated by the Management Committee of Food Integrity to make them suitable as research topics for procurement.

2) Report: Food integrity future research needs

This report described a mixed methods approach to identify existing and future food integrity knowledge gaps. Some of the gaps identified in the initial gap analysis have been included for research in the EU project FoodIntegrity. The remaining/emerging food integrity research needs can be divided into three main themes: Fraud prevention, methods and information to consumers. The results show that the priority research needs for the theme fraud prevention are: Fraud risk analysis; non-analytical prevention tools; and food fraud prevention integration in Food Safety Management Systems. With regard to the theme fraud detection methods, the priority research needs are rapid fraud detection tools; methods harmonization; and authentication of complex foods. Regarding the theme information to consumers, methods to provide the information needed by consumers and to increase consumer confidence also remain a priority. These identified remaining and emerging research needs provide funding bodies and researchers with a systematic framework to address future food integrity research.

WP4 Olive oil

The workpackage on olive oil addressed the current problems relating to this food product such as the heterogeneity of regulation, new tools for quality control, and the implementation on non-targeted methods in specific analytical problems. In the latter, we have studied the geographical identification, which is gaining importance, this authenticity issue being not addressed in the current standard methods defined in the European Union regulations and International Olive Council regulation. We have reviewed all the work carried out in past projects and we have planned the work as a continuation of those. In addition, we have established a procedure of evaluation of results to be reproduced in further works since the geographical identification needs future research to propose improvements in the methodology. The re-organization of the extensive information on olive oil was considered to be a critical part to identify research needs and to plan future works properly. A particular attention was given to heterogeneity in regulation since it causes many problems in international transactions. All this organized information and the results of a survey is being useful in current discussion on olive oil chemistry.

Key outputs

1) A knowledge base on the current situation of the olive oil market: this knowledge base includes a descriptive account of different olive actors' sensitivities to aspects as traceability, quality, PDO certification and analytical challenges. This knowledge base represents the current situation of cultivars and olive oil groves in different producing areas, including new producing countries (Chile, Argentina, etc.).

2) Evaluation of the utility of rapid techniques (non-targeted) in the particular application of geographical traceability of virgin olive oil: Clear conclusions have been extracted from a systematic intercomparison work by analysing the same samples with different methodologies. The techniques tested in this work were 13C-NMR, 1H-NMR, Raman, IRMS, FTIR, NIR, PLS-DA/LDA, U-HPLC-HRMS/MS, OPLS-DA.

3) A critical review of trade standards inside and outside EU has been produced. One of the current problems of olive oil market and international transactions is the heterogeneity in regulation. Therefore, it was necessary to identify and analyse the differences in the norms from the main regulation bodies around the world. For this critical review, the current trade standards from different national and international bodies were cross-tabulated and compared with the assistance of stakeholders for a better comprehension. The results have been published in a SCI journal, Grasa y Aceites: García-González et al., A study of the differences between trade standards inside and outside Europe, Grasas y Aceites, 68, 1-22, 2017 (DOI: http://dx.doi.org/10.3989/gya.0446171).

4) A report on the applicability of selected volatile markers of sensory defects to assess virgin olive oil quality. Thus, once the volatile markers were selected according to previous works, SPME-GC-MS/FID was applied at industrial scale with 48 real samples of virgin olive oil qualified with different sensory designations: Extra-virgin (without any detectable sensory defect), virgin (with slightly detectable sensory defects) and ordinary virgin or with manifest sensory defects.

5) A guideline for validating qualitative methods including statistical analysis. This guideline has been written by extracting the conclusions from the work of validating a method for geographical identification of virgin olive oils, although the guideline is applicable to any methodology with a quality response (binary answer, yes/no). This guideline has the aim of helping analysts to choose the best validation procedure that guarantees the robustness of the method for a well-defined objective**.**

WP5 Core Project Spirit Drinks
The Spirit Drinks Work Package has achieved significant advances in the development of tools, methods, resources and collaborative efforts to tackle spirit drinks fraud.

Key outputs:

- **Over 25 technology solutions investigated** as to their suitability for spirit drinks authentication. Particular successes include:
- the employment of highly portable UV-Vis spectrophotometers for the screening of the illicit addition of sugars to spirits;
- the successful use of highly portable pH and conductivity pens for identification of inadequately matured spirits or spirits diluted with non-deionised water respectively,
- the demonstration of the benefits (and drawbacks) of traditional laboratory equipment in more portable formats (transportable ESI-MS, GC-MS and low field NMR),
- increased speed, sensitivity and specificity in the analytical measurement of maturation related congeners (used to identify inappropriately matured counterfeit products), and;
- proof that Raman handheld spectrophotometers have the potential to authenticate spirit brands and identify illicit alcohol markers through bottle.

All of these advances have been either been employed within the industry or further developed post project work.

- **Identification of new analytical markers for spirit drinks fraud**. This includes illegal flavourings and flavouring carriers within certain spirit drinks. Within the Scotch Whisky

Research Institute (SWRI) these have been adapted into a routine method for spirit authenticity.

- **Identification of standard analysis methods for spirit drinks authenticity**. These were consolidated following a large stakeholder survey. This list informed the analytical methods recorded for spirit drinks authentication within the FoodIntegrity Knowledge Base (on behalf of Work Package 2) and also formed the basis for the chapter on Spirit Drinks within the FoodIntegrity Handbook.
- **Development of online training resource tools for spirit drinks authentication**. These include guidance documents, corresponding presentations for external training opportunities and supplementary information (e.g. a bibliography of papers detailing spirit drinks authentication techniques).
- **Creation of Spirit Drinks Authenticity Website** (password protected) situated on the FoodIntegrity website. This is designed for storage of outputs from the project, including application notes, papers, reports, presentations and resource training tools.
- **Creation of a Spirit Drinks Authenticity Network** with over 200 members.

WP6 - Reduce product misdescription in the seafood sector

Key outputs

Title: Seafood sampling and analysis report, D6.2
Description: The report outlines a citizen science experiment where volunteers collected 282 samples from 179 mass caterers in 23 European countries; this included around 90 different fish species. The DNA of the samples were analysed to see if the stated species was the same as the actual species. For 73 out of the 282 samples there was a mismatch between the stated species and the actual species. 26% misrepresentation of species in the mass catering sector is in line with similar investigations undertaken elsewhere, and this is one of the bigger investigations and biggest data sets of this type.

Title: Seafood misdescription database, D6.3
Description: The reporting of seafood misdescription incidents was originally meant to be based on manual input from correspondents. However, in collaboration with other projects with similar goals running in parallel (in particular http://www.authent-net.eu/), this task was significantly extended. A set of food fraud related keywords was developed, and a web crawler was developed which runs once a day, collecting stories online which match the keywords. Initially the web crawler had around 50% success rate when it came to identifying news stories relating to food fraud, and subsequent manual classification of stories into relevant / not relevant was needed. Because of machine learning functionality related to feedback from the relevant / not relevant classification, this success rate has gradually increased to around 90%, and at the time of writing more than 3200 misdescription incidents have been identified, around 600 of them related to seafood. The web crawler will be maintained and will run for several years after the project has finished, and the misdescription incidents can be found at the Food Authenticity Research Network Hub (FARNHub) available at http://farnhub.authent.cra.wallonie.be/news/index.

Title: Toolbox linking seafood claims to analytical and paper trail methods, D6.4 (incorporating D6.1, Seafood claims ontology)
Description: Food fraud is when someone intentionally causes a mismatch between the statement or claim made about a food product and the actual food product characteristics. This report brings together these two components; the statements or claims on one hand, and the methodologies for investigation and verifying the claims on the other hand. All typical claims related to seafood products are enumerated in D6.1. In D6.4, methodologies for verifying the claims are outlined; both analytical methods and paper trail methods. Analytical methods include analysis of morphological

characteristics, protein analysis, lipid analysis, DNA methodologies, and stable isotope analysis. Paper trail methods include material flow analysis and input-output analysis, as well as applications of traceability principles, blockchain technology, and Benford's Law.

Title: CWA 17369, Authenticity and fraud in the feed and food chain - Concepts, terms, and definitions
Description: This is a low level, voluntary European standard (a CEN Workshop Agreement (CWA)) which provides a clear, unambiguous, and consistent definition of key concepts and terms related to food fraud, including the terms "authentic", "record tampering", "product tampering", "adulteration", "addition", "substitution", "removal", "dilution", and the term "food fraud" itself. Delivering this standard was not an explicit objective in the FoodIntegrity project, but the content of the standard was very much built on the work done in WP6 (and the WP6 leader also led the CWA 17369 development process); in particular, the ontology development in D6.1 and the keyword development in D6.4.

WP 7: Consumer Awareness

The central objective of WP7 was to investigate consumer' attitudes and perceptions on food authenticity and traceability of a few selected products coming from Europe (infant formula milk, Scotch whisky and Olive oil) and to formulate recommendations to European companies which export food products regarding authenticity and traceability. The goal was to better understand the expectations and attitudes of consumers with regards to European food products, and to identify future market potential and niche markets for European products. The WP used a combination of qualitive and quantitative methodologies to reach its objectives. Initial stakeholder interviews were conducted in China to inform the development of consumer research instruments. An initial 'exploratory consumer study in China' aimed to identify Chinese consumer perceptions and attitudes towards selected food products from Europe, in particular in relation to attitudes related to authenticity and traceability. Six focus groups were held in three cities, Beijing, Guangzhou and Chengdu. A sub-sample of the focus group participants participated in repertory-grid and laddering interviews, conducted to better understand the psychological factors underpinning attitudes towards the 3 product groups. A quantitative consumer survey and choice experiments were used to identify consumer's preferences and willingness to pay for high quality and authentic EU products, and identify promising communication strategies regarding the authenticity of EU products. N=1000 participants from three Chinese cities (Beijing, Guangzhou and Chengdu) were included in the survey study. The results were validated through stakeholder interviews, and a set of 'stakeholder recommendations' will draw together the outcomes of the empirical work and provide marketing recommendations aimed at improving consumer information and trust in high quality and sustainable products tailored to the Chinese market.

Taken together, the results indicated that the occurrence of potential, or actual, negative public health impacts are not a precondition for the discovery of food fraud within the food supply chain to reduce have negative impacts on consumer trust and confidence in food chain actors and governance structures designed to mitigate the risks of food fraud. The discovery of food fraud acts as a signal to society that food safety and quality of foods and ingredients at all stages of the in the food supply chain is not secure. In addition, fraudulent behaviour may occur at all stages of the supply early in the supply chain, and relate to important consumer concerns which are difficult to verify unless effective and transparent traceability systems are implemented. For example, animal feed which has been conventionally produced may be fraudulently labelled as organically produced, or identified as being associated with shorter supply chains than is the case, in response to consumer demand. Persistent incidents of food fraud in China have resulted in low levels of consumer trust in the authenticity and safety of food that is domestically produced. We examined the relationship between the concerns of Chinese consumers regarding food fraud, and the role that demonstrating authenticity may play in

relieving those concerns. A systematic review of European attitudes was also conducted. Chinese consumers perceive food fraud to be a hazard that represents a food safety risk. Structural trust (i.e. trust in actors and the governance of the food supply chain) was not a significant predictor of attitude and intention to purchase authenticated food products. Consumers were shown to have developed 'risk-relieving' strategies to compensate for the lack of trust in Chinese food and the dissonance experienced as a consequence of food fraud. Indexical and iconic authenticity cues provided by food manufacturers and regulators were important elements of product evaluations, although geographical differences in their perceived importance were observed. The results from the European literature review suggested that similar attitudes were held by Europeans although further research is required to confirm this. Targeted communication of authenticity assurance measures, including; regulations; enforcement; product testing; and actions taken by industry may improve Chinese consumer trust in the domestic food supply chain and reduce consumer concerns regarding the food safety risks associated with food fraud. To support product differentiation and retain prestige, European food manufacturers operating within the Chinese market should recognise regional disparities in consumer risk perceptions regarding food fraud and the importance of personal risk mitigation strategies adopted by Chinese consumers to support the identification of authentic products. Targeted communication of authenticity assurance measures, including; regulations; enforcement; product testing; and actions taken by industry may improve Chinese consumer trust in the domestic food supply chain and reduce consumer concerns regarding the food safety risks associated with food fraud. To support product differentiation and retain prestige, European food manufactures operating within the Chinese market should recognise regional disparities in consumer risk perceptions regarding food fraud and the importance of personal risk mitigation strategies adopted by Chinese consumers to support the identification of authentic products.

Key outputs

Papers in refereed Journals see attached Main S&T supporting document

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WP8 Early Warning System

The goal of WP8 was to build a framework to enable assessment of probability of fraud in food chain/s and implement it in a user-friendly tool (Food Fraud early wArning systEM: FRAME-Fraud). The

component parts of the system are a text mining tool that identifies reports of food fraud based on the European Media Monitor, an Early warning system that identifies anomalous commodity trading patterns and Bayesian Networking based tool that predicts likely food fraud scenarios based on commodity type.

Key outputs

Text mining tool for identification of reports of Food Fraud based on the European Media Monitor.

The infrastructure provided by the European Media Monitor (EMM), was used to develop a food fraud tool (MedISys-FF) that collects, processes and presents food fraud reports published world-wide in the media. MedISys-FF is updated every 10 min 24/7. Food fraud reports were collected with MedISys-FF for 16 months (September 2014 to December 2015) and benchmarked against food fraud reports published in Rapid Alert for Food and feed (RASFF), Economically Motivated Adulteration Database (EMA) and HorizonScan. The results showed that MedISys-FF collects food fraud publications with high relevance >75% and the top 4 most reported fraudulent commodities in the media were i) meat, ii) seafood, iii) milk and iv) alcohol.

Early Warning System for identification of anomalous food commodity trading patterns

A novel food fraud Early Warning System (EWS) methodology for smart surveillance of international food supply chains was developed. This methodology was based on the concept of monitoring a large set of socio-economic, and related variables/indicators to detect anomalies in the food supply chain that can be a sign of emerging risks and fraudulent activities. Machine learning algorithms were used to process data and test the presence of anomalies using reference statistical distributions.
Alerts are generated on commodities using the Harmonized Commodity Description and Coding System (HS Code).

Bayesian Networking based tool that predicts likely food fraud scenarios.

A system was developed to predict the expected food fraud type for imported products for which the product category and country of origin were known in order to target enforcement activities. For this purpose, a Bayesian Network (BN) model was developed based on adulteration/fraud notifications as reported in the Rapid Alert System for Food and Feed (RASFF) in the period 2000–2013. In this period 749 food fraud notifications were reported and were categorised in 6 different fraud types (i) improper, fraudulent, missing or absent health certificates, (ii) illegal importation, (iii) tampering, (iv) improper, expired, fraudulent or missing common entry documents or import declarations, (v) expiration date, (vi) mislabelling. The data were then used to develop a BN model. The constructed BN model was validated using 88 food fraud notifications reported in RASFF in 2014. The proposed model predicted 80% of food fraud types correctly when food fraud type, country and food category had been reported previously in RASFF. The model predicted 52% of all 88 food fraud types correctly when the country of origin or the product-country combination had not been recorded before in the RASFF database.

WP10 Industry Integration

The workpackage has made a range of contributions to the project, assessing the value to industry of a range of FoodIntegrity outputs and contributing an industry input into S&T developments in many WPs in the project (e.g. co-author of two scientific opinions, contribution to the knowledgebase & Handbook WP2, Early Warning System WP8, WP18, WP20). In addition, it has produced the following WP specific Science & Technology results/foregrounds

1) Integration into databases from industrial perspective
Collected, selected and combined relevant information from either a number of different areas (vendor assurance, quality assurance, purchasing department, R&D, etc…) or a number of suppliers/co-packers along many different supply chains.

2) Recognition by normalisation/standardisation bodies of isotopic limits for the authenticity of tomato sauce, citrus juices and PDO hard cheeses.

3) "Testing on the field" of both confirmatory and high-throughput screening methods
Execution of the "testing on the field" of both confirmatory and high-throughput screening methods:
- Non declared enzymes in flours by LC-MS (Confirmatory)
- Meat speciation in processed food matrixes by LC-MS (Confirmatory)
- IRMS applications to frauds in wine-juices-tomatoes-cheeses (Confirmatory);
- Durum wheat traceability by biomolecular strategy (Confirmatory)
- Omics technologies for honey and/or meat authenticity (Confirmatory)
- Emulsifiers as unlabelled ingredients by multi-approach (Confirmatory&Rapid)
- Oregano/herbs authentication comprehensive strategy (Confirmatory&Rapid)
- Elemental fingerprinting for tomatoes authenticity by LIBS (Rapid)
- Accessible LIBS technology to verify origin of dairy products (Rapid)
- NIR at entrance/on production line wheat & flour chain (Rapid)
- Authentication of meat products by portable vibrational spectroscopy (Rapid)
- Tuna/fishes authentication on the canning line by RPA technology (Rapid)
- Tuna/fishes Vis-NIRS differentiation fresh-frozen (Rapid)

4) "Food Fraud Think Tank"
"Food Fraud Think Tank" initiative, supported by the GFSI (Global Food Safety Initiative), an industry-driven global collaborative platform to advance food safety.

5) "Industrial Markers for Quality and Authenticity"
Identification and integration into databases from industrial perspective of specific chemical and molecular biology markers relevant for the detection of specific frauds in specific food chains.

6) Reporting requirements for analytical methods used for food authenticity testing
Contributed to create a set of guidelines for production and use of authenticity data.

7) Food Integrity Training Program
Training program has been delivered in cooperation with well-established EU organisations in short-term training activities:
• Analytical tools for authenticity of raw materials in pasta, sauces & bakery (Barilla, Parma, Italy)
• 'REGULATORY & RISK ASSESSMENT CONCEPT' Frauds & adulterations management in strategic raw materials for pasta, sauces & bakery products & 'SENSORY & MANAGEMENT CONCEPTS' Consumers science & Industrial management skills useful to assure food integrity (Barilla, Parma, Italy)
• Rapid tools for food integrity: testing on the field (Barilla, Parma, Italy)

8) Food Integrity Industrial Integration Infographics & App
A complete set of infographics in in the main European languages concerning foods, risks, analyses and specific case studies, available online through FI channel. A parallel FoodIntegrity-APP has been made available on both Android and IOS platforms for mobile devices.

9) Food Integrity Industrial Integration Video-tutorials

Industrial Integration video-tutorial (and other parallel educational video-cartoons) to give a look into FoodIntegrity industrial perspective work.

10) Food Integrity Industrial Integration Vulnerability assessment & Guidelines

Rationalization of all the relevant "industrial outcomes & tools" of the FoodIntegrity project.

WP11: Dissemination & Knowledge Transfer

The FoodIntegrity project undertaken a wide range of dissemination and training activities in order to inform the widest audience (composed of stakeholders as well as scientists, official authorities and the general public) about the actions performed during the project lifetime and the outcomes achieved to maximize impact in terms of improving food integrity.

The dissemination activities enabled excellent visibility of the FoodIntegrity project and informed the widest possible international stakeholder audience. The FoodIntegrity results will be made accessible and usable to different kinds of stakeholder groups, SMEs and industry in the agro-food sector, national and European risk assessors, policy makers, public authorities, EU (in general), in order to optimize the mechanisms and strategies with regard to food quality and safety and risk assessment.

In the educational context, developed complex training program with short- and long-term training / mobility activities in advanced analytical technologies and other specific knowledge developed / generated within the project framework to the project consortium members and external end-users at organisation / local / national level for scientists, academia, researchers, control labs etc. should enable knowledge transfer among potential end-users and transmission the scientific knowledge generated in the project.

- **FoodIntegrity** Dissemination and Communication Strategy & Plan developed
- FoodIntegrity project website www.foodintegrity.eu developed and maintained
- Social network account on Twitter (@FoodIntegrityEU) created and fed by tweets from the project partners and apart
- Wide range of dissemination and communication activities at a range of international and national events to a broad scientific and general public delivered; various types of audience from many countries of Europe and worldwide impacted
- Many other dissemination and communication activities delivered such as (co)organisation or support / partnering of various events, radio/TV/newspaper interviews, education and outreach activities, etc.
- Series of scientific papers on the project achievements published and available on the website, tens in preparation
- More than 50 project partners contributed to the FoodIntegrity Handbook: A guide to food authenticity issues and analytical solutions (2018) edited by Jean-François Morin & Michèle Lees; published by Eurofins Analytics France, Nantes, France. ISBN: print version 978-2-9566303-0-2, electronic version 978-2-9566303-1-9 (https://doi.org/10.32741/fihb)
- 8 e-Newsletters published and available on the website
- Series of Open Days, Demo-corner activities and FoodIntegrity supported sessions organised as satellite events of the well-recognised international symposia (International Symposium on Recent Advances in Food Analysis (RAFA 2015 and 2017), Belfast Summit on Global Food Integrity (ASSET 2018)) and FoodIntegrity conferences in 2016, 2017 and 2018

- 5 closed consortium meetings followed by a food integrity stakeholder events “Assuring the integrity of the food chain” organised and altogether attended by 1 200 delegates from countries worldwide representing a range of stakeholders from food control authorities, EC representatives, governmental bodies, trade organisations, scientific community, food industry, control labs, media and producers of analytical instrumentation and consumables; information on FoodIntegrity conferences available on the website
- For the efficient knowledge transfer on developed technologies and other information generated within the project framework, training network has been established, consisting of comprehensive training program, young scientist mobility program, establishing a training school, organisation a series of the workshops.

WP 13: Consumer and Brand Protection in Complex Foods from Protein Signatures Using Mass Spectrometry

This workpackage had the primary aim of developing and demonstrating MRM-MS methods for verifying food authenticity via the protein component in complex multi-ingredient foods, typified by pizza. An imperative throughout has been to develop methods that high-throughput, straightforward and cost effective. The sample preparation protocols have needed to overcome a variety of issues, e.g. matrix effects, whilst keeping to the brief of suitability for subsequent transfer into industry.
We have successfully achieved practical protocols for a variety of complex foods, to the extent that these are now being offered to the food sector commercially. We have also established the groundwork for further methods in the future, especially in the area of universal markers.
Our work has been disseminated through a range of mechanisms, not least papers in the peer-reviewed literature (two already published, additional papers in preparation). We will continue to publicise our workover the coming months, through additional channels such as trade journals and social media.

Highlights:

- Protocols for authenticating the main ingredients of a pizza, a typical ‘complex’ food. Specifically demonstrated for cheese (mozzarella).
- Demonstration of the ability to differentiate between tomato varieties and between skin versus flesh versus seed via peptide markers.
- Protocol for the species determination and quantitation for cured meat products, a unique complex food product.
- Protocols for relative quantitation of raw and cooked meats in mixtures and a range of food products and matrices.
- Protocol for quasi-untargeted adulteration detection in meat mixtures using a global marker approach
- Ring trials carried out by all partners on a range of different samples, which validated the protocols and the ability to transfer between MS platforms.

Key outputs:

- Publication: “MRM–MS of marker peptides and their abundance as a tool for authentication of meat species and meat cuts in single-cut meat products” Nalazek-Rudnicka et al (2019) https://doi.org/10.1016/j.foodchem.2019.01.007

- Confidential report to industry partner Kummer on the topic of authentication and species determination in cured meat products

- Publication: “Quantitative authenticity testing of buffalo mozzarella via αs1-Casein using multiple reaction monitoring mass spectrometry” Gunning et al (2019) https://doi.org/10.1016/j.foodcont.2019.02.029

WP14 From nutritive seeds to complex foods: Markers of composition and stability along the food production chain. Case study: Chia (Salvia hispanica L.), flax (linseed; Linum usitatissimum), sesame (Sesamum indicum) and bakery products containing these seeds.

We found diverse markers to verify the authenticity of chia, flax and sesame seeds and, its presence In complex foods (bakery products containing chia seeds or defatted chia). We verified the stability of chia, flax and sesame markers considering important nutritional components and proposed markers (chemical and molecular), along the production chain (production of bakery products containing these seeds, single seed or mixtures). The tool-kit, constructed from diverse markers (genetic-molecular, chemical, etc.) enable the verification of the presence and relative amount of chia, flax and sesame for regulatory purposes using blind commercial samples (bakery products containing seeds). Thus, we developed a tool-kit that can be used to verify the presence of these nutritive seeds in commercial bakery products, which could be extended to the verification of other components of nutritional importance in complex foods, including processed foods, improving consumer´s trust and the certification of composition by food-industry. The method could be used for regulatory purposes after some extra fittings.

Three tools developed using both raw seeds and lab-scale cookies were tested using commercial bakery products obtained from different shops in Argentina. Developed methods were able to positively identify the presence of studied seeds in commercial products claiming their presence in the label. No products containing false declaration in the label were found. The use of both chemical/metabolomic and DNA-based methods were useful for both screening and confirmatory purposes. Detailed results were reported in the Deliverable 14.3.

Main outcomes are as follows:

1.1. We have **three independent methods** to verify the presence of chia, flax and sesame **seeds in complex foods** (GC-MS+ Machine Learning / LC-MS+ Chemometrics / RT-PCR of rbcl ribosome gene). These three methods perform quite well with cookies and other bakery products.
1.2. Identification of metabolic markers is possible considering the complexity of chemical reactions during food processing, especially baking (non-target vs. target analysis).
1.3. Combination of metabolic markers (non-target) with other molecular (genetic) and target markers brings better results to fully identify the presence of nutritive seeds in baked products (complex food).
1.4. **Integrating three independent methods into a “tool kit**” enable both screening and confirmatory methods, mainly non-target methods for screening and target methods for confirmatory issues (quantitative levels could be necessary for regulatory purposes).
1.5. This tool-kit should enable detection of frauds in foods containing these nutritive seeds, also improving the nutritional information to consumers on the presence of bioactive compounds in such foods

WP 15 FISHUB Fish Identification Software Hub

The main objective of the F.I.S.HUB project was to develop a software tool to be used in the field, by both professionals and inexperienced people, to detect species substitution. WP15 produced as output a software to classify 22 fish species through a picture taken by a mobile phone. This software is accessible through an app that is downloadable for free by any user. The detection of substitution

fraud in fish can be carried out easily through this new app, by inexperienced consumers too. Moreover, a secondary output was the evidence that the SciO portable NIR, a low-cost device purchasable by anyone, is a promising tool to identify species in fish fillets and could be mainly used for large scale screening at food industry level.

The FISHUB App has been developed as foreseen in the project. It is a mobile interface to the FisHUB database and classification server that were developed during the project. The FISHUB App allows, in this first release, to take or select a picture (from the phone photo album), to select the corresponding species, submit them to the FISHUB classification server, and finally display the classification results. The App also allows browsing the species covered by the FISHUB project and, for each of them, display a representative photo and its main morphological characteristics. The FisHUB App is available in the Apple Store and it has been submitted to Play Stores. It is also available in beta version at the website www.fishub.eu.

Impact: it can be used worldwide by food industries, consumers and controllers to detect fish substitution frauds. Its impact can increase with the implementation of the database.

WP16 Check X - Improving Supply Chain Integrity through Data Sharing

The project concluded that application of Check X in the European food industry to detect and/ or prevent food fraud is feasible and financially viable, while also identifying technological alterations required to the integrity solution. In addition, recommendations were made regarding the sales of Check X, which are mostly implemented. The impact that the project will have in the future is an increased implementation of Check X by companies as well as increased system-wide Implementation by authorities such as governments, the EU, business sector associations or certification scheme owners. This will result in a reduction of food fraud in the organic sector particularly and the European food supply chain as a whole, as well as increased food integrity of organic products in the European food sector.

The analysis whether Check X developed as Check Organic for the organic sector can serve as a blueprint for all other commodities was answered positive and can thus be applied as a non-analytical supply chain integrity tool in the food industries at large. The possible applications will support the EU's strategy to fighting food fraud in commodity chains within the EU as well as for imported products in regional and global supply chains. Check X will also allow a more targeted application of analytical tools.

1. Check X can support companies with their food fraud risk mitigation measures: companies can apply the Internal Audit Compliance Management Module of Check X, the Supply Chain Monitor, and the Supply Chain Volume Monitor in their own supply chains to support existing fraud risk mitigation measures or put into effect new fraud risk mitigation measures.

2. System-wide application of Check X may enable authorities such as governments, the EU, business sector associations or certification scheme owners to more effectively detect and prevent fraud in the industry that they work in.

3. There are three pre-requisites for successful Check X system applications:
   - All supply chain actors within the system must participate,
   - All production and trade must be recorded, and
   - All relevant product qualities must be recorded.

A high percentage of relevant supply chain actors are enough to qualify as "all", as minor supply chain actors are either squeezed out of the system or are forced step by step to participate. Building a Check X system should not be prevented by an "all supply chain actors must participate" dogma.

4. A technological adaptation regarding the anonymisation of data for supply chain actors in Check X is desirable due to the participation of various participants with distinct roles.
5. There are two factors that determine the complexity (and therefore cost) of set-up and ongoing support: the number of data sources of compliance data, and the number of data sources of supply chain data.

6. There are five factors that determine the technological specifications of the Check X application, and therefore may or may not trigger technological adaptations of the current system: the number of standards included in Check X, the required product taxonomies, the way of operator identification, the type of primary production and requirements for mass balance calculation, and the product forms and product qualities, and requirements for mass balance calculation. In addition, the geographical scope and regional characteristics of the application may come into play.

7. From the cost-benefit survey with users of the FederBio Integrity Platform (FIP) in Italy (an existing Check X application), we concluded that the FIP is effective at preventing fraud, yet due to the current unsatisfactory level of policy harmonisation, the FIP is not working as smoothly as it should. However, once fully adopted by all supply chain actors and certifiers, the FIP has great potential in terms of time and cost savings for participants.

8. The researchers identified a few challenges in conversations about Check X done as a part of the feasibility study; interview partners often struggle to identify what type of Check X application may be best for their organisation. The researchers concluded that future efforts should focus on successful communication about Check X and identified three recommendations to address this challenge: To revisit and sharpen the communications strategy for Check X, to map the Check X sales process and develop sales tools, and to sharpen the online presence of Check X.

WP17 – Feasibility Study Information Sharing & Analysis along the Food Chain to identify Emerging Food Integrity Issues. Main Science & Technology results

1) Overview of information sources and analytics, and systems of sharing.

In several desk study reports a detailed overview was produced on the type of information and the sources that may contain (early) signals of food integrity issues, as well as on the systems and types of sharing under current and expected information technology developments. A potential architecture for such a system for the food chain to share information on potential food integrity issues was suggested, taking into account the context and conditions for (pre-competitive) information sharing between stakeholders in the food chain (see also next item).

Also, an overview was produced on how to be able to analyse the information available to find the early signals of and emerging food integrity issues. Such analyses of large volumes of information need both automated searches (e.g. data mining) and expert judgment and assessment.

The major conclusion is that the technical potential for an information sharing system is broadly available, as well as systems for the automated analysis (and pre-selection) of relevant data and

information. The set back is the availability of the information, for which sharing is a prerequisite, and this might lead to a basic chicken-and-egg discussion. Also, a good model for the assessment and judgment of early signals still needs to be developed.

2) Stakeholder attitudes and conditions

A Delphi-type survey was performed to establish the attitude of stakeholders towards the food integrity problem and information sharing as a method to prevent or prepare for food integrity issues. This survey was done in three rounds, two through the internet and one workshop (held in Belfast, UK, in May 2018). The purpose was to make an inventory of hurdles and solutions, as well as (side) conditions for an information sharing system.

The major conclusion is that stakeholders appreciate the idea of sharing information that may lead to the early identification of food integrity issues, but differ in the side conditions under which to share and the extent of data and information to share, and at what timing. Some conclusions on the side conditions can be drawn, e.g. a third party should be responsible, information sources should be as broad as possible (incl. authorities), and, obviously, confidentiality needs to be guaranteed.

WP18 "INTELLItrace"

The main focus of the WP18 actions was based on the harmonization and validation of non-targeted methods applied to the protection of foods from frauds. The final goal, following an articulated and deep discussion about validation procedures (also involving Partners from other WPs within FI Project), was the drafting of a suggested guidance for the validation of non-targeted methods. More details are reported on the following Key outputs.

Key outputs

1) Harmonization of non-targeted analytical methods

This topic was a strategic preliminary work for the Units involved in WP18. Harmonization of non-targeted methods aimed at correctly classifying food commodities according to defined characteristics is a key topic, particularly regarding the comparability of the results when they are applied by different operators in different laboratories (proficiency tests, interlaboratory trials). Chromatographic, electrophoretic, spectroscopic and DNA-related methods were considered. This part of the work allowed identifying criticisms regarding the application of some techniques (particularly non-traditional techniques here considered, e.g. DART-MS analysis). The outputs from this collaborative work are principally related to i) the setting up of shared and harmonized protocols of analysis and ii) the identification of the limits (criticisms and biases) regarding the application of specific analytical methods to some food matrices.

2) New insights about applicability of non-targeted methods to selected food matrices (salmon; rice; honey; saffron) in order to protect them from food frauds

The general lay out of the WP project was based on two main blocks: i) analysis of data sets previously produced within other Projects and ii) the generation of new data sets. The analysis of the "old" data in many cases led to problems often related to the retrieval of raw unprocessed data, as well as to the comparison among sets of data produced under different experimental conditions. The newly produced data sets (particularly regarding some specific models, as in the case of identification of farmed and wild salmons from different geographical origins) allowed to new insights on food composition and on the setting up of new analytical/post analytical protocols useful to track the origin. Moreover, compositional (and genomic) data related to the matrices here considered (saffron, rice, salmon, honey) were produced.

3) Deep evaluation of Artificial intelligence-based methods for post-analytical processing of data

A fundamental aim of the Project was the in depth analysis of the more common algorithms useful to process data sets (post-analytical processing), particularly regarding the selection of the more performing classifiers useful in this area. The main outcomes in this line have been the evaluation of the suitability of feature selection methods based on correlation of the considered class, and of supervised machine learning algorithms, even in presence of a limited number of samples. The standard evaluation process adopted in Machine Learning has also been employed as a main inspiration point, in order to define the final guidelines objective of the project.

4) Guidance on the validation of non-targeted methods

The final goal of the WP18 activity was the drafting of the Guidance for the validation of non-targeted methods applied to assess food integrity, related to the analytical and the post-analytical steps of the process. The draft of the Guidance, produced by the Partners of the WP18, but deeply discussed among other Partners of FI Projects (mainly FERA, BfR and WUR), has been published as Deliverable, taking into account the precise description of the validation process (step by step), as well as providing some examples of validation. This final document was prepared considering the scientific literature (previously published position papers), best practices protocols, standards and regulation currently available. The guidance is intended as a series of general suggestions and remarks useful for those operators who approach non-targeted methods for analysing foods.

WP19 NIRS microsensors and ICT platforms

Over the last two years, a NIRS system (MicroNIR Onsite, Viavi Solutions, USA) has been optimized and trained by members of the UCO (University of Cordoba) research team to collect spectra from pigs' fat tissue directly in the slaughterhouse for classification and characterization purposes. Main Science & Technology results/foregrounds are described below.

- "Optimisation of a portable miniature spectrometer for the on-site analysis of individual pork carcasses, at the slaughterhouses". The spectral acquisition of fat tissue using portable NIR sensors at the slaughterhouse environment was optimized.

- "Transferring the previous spectral databases from at-line instruments to the portable ones, and updating the models with new samples for the prediction of fatty acids content and for the authentication of the premium commercial category". A large dataset of Iberian pig spectra analysed in a monochromator lab instrument was successfully transferred to a miniature low-cost and real-time miniaturized NIR instrument using a methodology based in the concept of "spectral matching".

- "Evaluation of advanced chemometric strategies for increasing the prediction model's robustness". Both quantitative and qualitative approaches were used. The portable MicroNIR spectrometer results for fatty acids composition were found to be similar than a lab NIR instrument. Results clearly demonstrated the feasibility of using the MicroNIR for on-site classification of carcasses.

- "Design and building of an app to access the NIRS web virtual environment through cloud computing from mobile/tablet devices for the instantaneous monitoring of Iberian pig quality". An app to access the NIRS web virtual environment through cloud computing from mobile/tablet devices for the instantaneous monitoring of Iberian pig quality has been designed and built. A patent is being prepared for submission. A connection protocol between the mobile device and the platform, for enabling the consumer access to the information of a product identified by a QR code (related to fatty acids composition, market category, origin or production system) has been developed.

- “Wider applications of NIRS”. Guidelines for food industries that want to implement NIRS technology have been drawn. The potentialities of NIRS for other uses in food authentication, in particular focused to other applications in the meat industry have been studied.

WP20 “Integrity of complex foods: innovation in analysis and communication”

We have constructed an annotated data base which allowed us to evaluate the scientific literature and choose the best 6 DNA based analytical methods to be used in an industrial environment to test complex food products. The experimental results of the use of the 6 different methodologies chosen on the two test products (Bolognese sauce and dried raw ham tortellini) and the analysis of the process flow diagrams allowed us to choose among them the most appropriate to be positioned the in critical points along the process flow, in order to detect possible frauds or adulterations of specific ingredients.

All these results have allowed the compilation of a list of guidelines and recommendations for industrial stakeholders.

We have also investigated the best tools and channels for communicating integrity of complex foods through a consumer study performed in Denmark and Italy. In general, the interviewed consumers were not used to look for QR codes when they were shopping and they thought that it would take too much time. They said that they want to be sure that it gets useful information and not that it only take them to a homepage. Both consumers in Italy and in Denmark consider themselves as persons that are interested in what the food contains and are interested to know the origin of the food. Among the Danish consumers there was a higher share of consumers that was searching for new food products while Italian consumers seems to be somehow more positive towards the QR code use.

All these results have allowed the compilation of a list of guidelines and recommendations to stakeholders to make a good and useful QR code.

Key outputs

1) Production of the Database.
To assess critically the scientific literature reporting application of analytical DNA methods to authenticity testing of complex food products, a bibliographic research was performed using PubMed and EBSCO libraries by keywords. We have analysed about 120 articles, published in the last 20 years. This database was used to understand the current state-of-the-art of know-how and methodologies.

2) Set up an evaluation of a panel of 6 analytical methods on complex food products.
Although more advanced molecular biology techniques (e,g, Next Generation Sequencing analysis, digital PCR) have been developed these are still too expensive and/or difficult to be routinely implemented in an industrial process line. For these reasons we have chosen to focus on traditional and real time PCR methods in order to provide the industry with a customized set of methods able to verify the compliance of food with regard to animal, plant and spice species declared on the labels. The 6 methods tested are: 1./2. endpoint singleplex and multiplexing PCR; 3./4. quantitative PCR (SybrGREEN/TaqMan probes) for bovine and porcine species; 5./6. endpoint singleplex/multiplex PCR for plants and spices.

3) Definition of the Process flow diagrams for the production of complex foods (ready-made sauce, stuffed pasta dish).
Process Flow Diagrams of two complex foods were analysed: ready-made sauce (Bolognese sauce) and stuffed pasta (Tortellini filled with meat). Then, these tests have been positioned in critical points

along the process flow in order to detect possible frauds or adulterations of specific ingredients. These results have allowed the compilation of a list of guidelines and recommendations for industrial stakeholders.

4) Consumer study for the identification of the best tools and channels for communicating integrity of complex foods to consumers.
To investigate the best tools and channels for communicating integrity of complex foods a consumer study was performed in Denmark and Italy. In general the interviewed consumers were not used to look for QR codes when they were shopping and they thought that it would take too much time. They said that they want to be sure that it gets useful information and not that it only takes them to a homepage. Both consumers in Italy and in Denmark consider themselves as persons that are interested in what the food contains and are interested to know the origin of the food. Among the Danish consumers there was a higher share of consumers that was searching for new food products.

5) Guidelines to make a good and useful QR code.

6) Guidelines and recommendations for industrial producers of complex foods.
We have set some guidelines and recommendations for quality control and analytical strategies, in order to inform producers of ready-made multi-ingredient food products, to highlight how a supply and production chain can be checked to look for vulnerabilities and criticalities and how to compute a cost-benefit analysis of the resulting procedure.

These guidelines have been developed as tools for the control of the critical points along the production process of the two complex food products studied.

WP21 Demonstration

WP21 aims at carrying out demonstration activities linked with WP 15 & WP19, so the main Science & Technology results/foregrounds are the same as the ones described in WPs 19 and 15.

In particular, regarding demonstration activities of WP 15, we aimed at testing the accuracy of the software in correctly identifying the fish families included in the database, making a validation on site, carried out by people with different levels of experience, analysing possible variables influencing the performances of the software. The tool was cross-validated with the DNA analysis carried out in laboratory.

As far as the results of WP 21, demonstration assays were undertaken in the slaughterhouse with the final solution and an on-site evaluation of the advantages and limitations was conducted. The system developed in WP19 was industry tested with samples belonging to 12 different producers and collected in a new season (2018). The parameters that were selected for industrial trials were the commercial category and main fatty acids profile, the most representative and directly related to the ham quality. As this methodology is dynamic the models will be refined annually and improved with additional samples.

Strategic impact

FOODINTEGRITY was specifically designed to maximise the impact of EU research on food authenticity and quality during the last 20 years. Its main purpose has been to consolidate existing research and be an international focal point that will drive the research and implementation of a transparent food assurance process for European products.

FOODINTEGRITY has enhanced the value of the European Agri-food sector by contributing to a visible food assurance infrastructure, endorsed by major stakeholders and with high global visibility. Not only can European producers provide authentic, high-quality food from sustainable production, but they are able to document this authenticity with reference to accepted and transparent methods, both paper trail and analytical. This visibility will not only ensure that European food products are better protected from counterfeiting and fraud due to state of the art systems and processes, but will also ensure that the legacy from the world's leading food safety and quality systems is preserved/enhanced.

Expected Impact from original call in the table attachment

Establishing "Food Integrity" within a European Agri-food strategy

FoodIntegrity has played a major role and had considerable impact on establishing "Food Integrity" within the EU. For example, it has contributed to the establishment of DG SANTE FoodFraudNetwork https://ec.europa.eu/food/safety/food-fraud/ffn_en, when FI was presented to the network in 2015. Similarly, close links have been established between FI and the Food fraud Knowledge Centre recently formed within the JRC in 2018 https://ec.europa.eu/knowledge4policy/food-fraud_en. FI has contributed to policy discussions concerned with Olive oil (DG Agri), Spirit drinks (DG TAXUD) and seafish (DG SANTE, DG MARE). FI members were instrumental in setting up the Food Industry Intelligence Network (FIIN), the first industry body to fully embrace data sharing between industry partners.

In combination with Authent-net http://www.authent-net.eu/ it has worked with EU Member States to produce a joint strategic agenda and also to provide a standard set of terms and conditions with respect to food fraud. This latter aspect has involved considerable input from FI participants into a CEN WorkShop Agreement (CWA) that has been recognised internationally as the first step in the potential global harmonisation of a set of terms and conditions for food fraud.

The considerable international outreach that FI has had has enabled the dissemination of this "EU model" of assuring food integrity (and the related added value) to other countries and continents and is being adopted by many as the most useful approach for addressing food fraud while at the same time protecting the added value of their local agri-food economy.

Working with control authorities and industry to develop and promote the concept of food Integrity

FoodIntegrity the project, has been very successful in developing and promoting the concept of Food Integrity, such that the term is now used by most stakeholders concerned with mitigating food fraud. The FI stakeholder platform established in WP1 has brought together major players from both the regulatory bodies and the food industry to ensure and promote the future of authentic, high quality European food production. Similarly, the FI conferences and workshops continue to attract multi-stakeholder audiences and provide valuable support and insight to both control authorities and industry. A good practical example is the FI Training programme where laboratory analysts from both industry and control authorities have taken part in training to access the state of the art in detection

and mitigation procedures. Control authorities (Food Standards Authority Ireland) and industry (Food & Drink Europe) have occupied advisory positions within the project and have ensured the project has maximum impact on the respective stakeholders.

Developing the tools and systems needed to assure the integrity of the agri-food chain

A main focus of the project has been to develop new tools and systems, i.e. not just analytical methods. Indeed FI was the first to include a range of multidisciplinary approaches to the problem –some of which are:

- Best practice for assuring the integrity of complex foods
- The use of non-analytical (method) approaches to authenticating foods e.g. mass balance, data sharing, mapping of claims, citizen science approaches, early warning systems that anticipate fraud
- Open source knowledgebase of information on analytical methods
- Demonstration of in-situ analytical systems for assuring product quality and by so doing, its authenticity and provenance.
- Exploring the concept of data sharing through both conceptual and IT based practical solutions (Check X)
- Developing the science and quality assurance infrastructure around non-targeted analysis to enable it to be implemented by industry and control authorities

A key issue is that these methods and tools should be transparent and readily available to all stakeholders, not only in the scientific domain. Important scientific solution/damage mitigation in the agri-food chain of FOODINTEGRITY is the improved interaction between stakeholders and the scientific world, where scientists develop authenticity tests and make them readily available in the food chain to assure the integrity of foods for European (and non- European) consumers.

Establishing an expert group(s) to advise on food authenticity/fraud issues

Considerable resources have been placed within FI to mobilise what probably is the world's largest body of expertise in food authenticity. For example, the FI network comprises over 300 experts that have been used to: advise on the scope and content of 8 scientific opinions, inputted into the various FI workshops throughout the lifetime of the project, input into future strategy, aiding in gap analysis and convening independent expert panels on relevant topics. FI has contributed its experts to a wide range of formal expert committees and task forces around the world, e.g. Codex, ISO, CEN, GFSI, ILSI. Until the advent of FI the resources and visibility of such expertise was very low- a key impact of FoodIntegrity is that the visibility of such expertise is now very high.

Establishing an early warning system that will identify emerging risks with regard to food fraud

FoodIntegrity has led the way in terms of developing systems and tools that look to anticipate food fraud and the associated emerging risks. A dedicated WP has successfully developed systems that can: 1) predict the type of fraud detected from minimal information 2) provide risk profiles for food and ingredients in the food supply. This latter system is now a commercial service at Fera (see WP8).

Extensive training and knowledge transfer activities

- Wide range of dissemination and communication activities at a range of international and national events to a broad scientific and general public delivered; various types of audience from many countries of Europe and worldwide impacted.

- Series of Open Days, Demo-corner activities and FoodIntegrity supported sessions organised as satellite events of the well-recognised international symposia (International Symposium on Recent Advances in developing countries e.g. a pan-African workshop that took place in South Africa in June 2018.

- 5 closed consortium meetings followed by a series of food integrity stakeholder events "Assuring the integrity of the food chain" organised and altogether attended by 1 200 delegates from countries worldwide representing a range of stakeholders from food control authorities, EC representatives, governmental bodies, trade organisations, scientific community, food industry, control labs, media and producers of analytical instrumentation and consumables; information on FoodIntegrity conferences available on the website

- For the efficient knowledge transfer on developed technologies and other information generated within the project framework, *training network has been established*, consisting of comprehensive training program, young scientist mobility program, establishing a training school, organisation a series of the workshops.

See WP11

An enhanced understanding of how food fraud can affect the purchasing behaviour of consumers in developing countries with regard to European food.

FI has undertaken extensive research in China and has undertaken a systematic review of European perceptions. in this area with the following findings.

Food fraud is the failure to provide assurance of food authenticity, safety and quality (collectively called food integrity), and usually involves deliberately deceiving consumers to increase profit. Whilst this can reduce product quality, breach cultural or religious norms, or even compromise food safety and cause illness or harm it can also decrease price and enhance sensory quality, making products more attractive to consumers. The occurrence of a food fraud incident has negative impacts on consumer perceptions of food safety and their trust in food safety governance systems, from the perspective of both the prevention of food fraud and its mitigation. However, increased vigilance and detection across the food chain, as well as improved measures to prevent food fraud, will increase consumer confidence. Consumers can also take measures to protect themselves including preference to purchasing European products, and utilising specific packaging indicators to guarantee authenticity. The development of effective communication strategies with consumers is essential in the maintenance of consumer confidence. In addition to having a major scientific impact in this area this research has also provided end-user guidance to industry about how best to market their products in China.

Establishing the 10 year research priorities required to support the integrity of the European Agri-food chain

FoodIntegrity has undertaken extensive gap analysis, consulted widely across many countries and stakeholders to produce strategic research priorities. These have been presented and relayed to the appropriate stakeholders and will inform Horizon Europe and EIT funding agendas.