Chapter 8

Intelligent and Smart Packaging

Marcello Nicoletti and Paola Del Serrone

Additional information is available at the end of the chapter

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Abstract

Urgent need of increased food production and availability are crucial in humankind future. A key aspect concerns the food preservation, wherein packaging is a main aspect. Packaging is still in a primitive form, utilized as a way to separate food from environmental conditions, not considering the inside situation. Improvement of packaging means less cost, more food available, and waste decrease. Several solutions are emerging to face this challenge. They are focused on three aspects: the antimicrobial agent; the packaging material; and the technological implication in the final production of packaging. Biotechnology is expected to play a central role in the future food to solve central points, as retain integrity and actively prevent food spoilage. In this phase, several projects are moving, still waiting to converge in adequate products. The galaxy of smart packaging is rapidly moving and increasing in researches. This phase represents a chaotic period of several proposals production and tentative in solving the food preservative problems, using new technologies and advanced techniques, like nanotechnology. Waiting the collapse into a central paradigm, it is interesting and useful to follow the scenario of researches on smart packaging based on natural products here reported.

Keywords: packaging, food waste, food shelf life, food-borne pathogens, food preservation

1. Introduction

'Feed the Planet. Energy for life' was the theme of World Expo 2015 in Milan city that tackled the great problem of sustainable progress and production of future foods. The event projected the feeding as main challenge for humankind and showed the extreme urgency of elements of innovation in technology and science connected to the field of food, in order to contrast feed problems that still today plague several areas of the world. Food production is growing rapidly, as a result of the increasing demand. The global meat production and consumption are supposed to increase from 233 million tonnes (2000) to 300 million tonnes (2020), and milk from 568 to 700 million tonnes over the same period. Egg production should also increase by 30% [1]. The challenge is the possibility of production of enough food for the incoming seven billions of human inhabitants of the planet.

This forecast shows in particular a massive increase in animal protein demand, needed to satisfy the growth in the human population, wherein billions of people ask for an increase of caloric input and better food. The considerable and increasing demand for animal protein is focusing attention on the sources of feed protein and their suitability, quality, and safety for future supply. In addition the quantitative production aspect, there will be a need for considerable increase in feed manufacture, requiring a thriving, successful and modern feed industry, including a key aspect concerning the protection and preservation of the produced and marketed food.

This aspect is strictly related to the safety issues, which will remain paramount in the mind of consumers following recent food crises. Continuing investment is needed in quality assurance programs to gain market access for animal products and to retain consumer confidence [2].

Biotechnology is expected to play a central role in the future food, in order to solve central points, as to retain integrity and actively prevent food spoilage (shelf life). Nowadays, packaging is still mainly a primitive form to separate food from environmental conditions, not considering the inside situation. Increase of the shelf life means reduction of cost and waste. Nowadays, simple material made of paper or plastic are used for packaging. These materials are main part of waste in industrial country and the cost for recycling is increasing as well as the damages to the marine environmental. 'Smart packaging' is focusing the interest in possible solutions. Smartness packaging covers a number of functional methods that can be tailored depending on the product being packaged, including several types of food, beverages, pharmaceuticals, household products, etc. Examples of current and future functional 'smartness' would be in packages that can not only actively prevent food spoilage (to add shelf life) but can also face other aspects in order to reduce the food waste, and eventually maintain, and enhance product attributes (e.g. look, taste, flavor, aroma, etc.), responding actively to changes in product or package environment, confirming product authenticity, and acting to counter theft.

2. Smartness and packaging

The galaxy of smart packaging is rapidly moving and increasing in research and proposals. We can consider this phase as a period of production of several proposals and tentative in solving the food preservative problems, using new technologies and advanced techniques recently available, like Nanotechnology and Molecular Biology. Waiting the collapse into a central paradigm, it is interesting and useful to follow the scenario of research on the subject and the lines of different emerging products.

The novel sustainable solutions in packaging must consider the need for ensuring the safety and quality of food and reducing losses and minimize the environmental impact. As a matter of fact, food packaging plays a crucial role not only in preserving food during distribution and storage from farm to fork but it also contributes to the generation of waste. The aim of modern food packaging systems is focused on the potential capacity to extend the shelf life of perishable foods, by reducing the need for additives and preservatives, and at the same time considering changes in quality. Several methods and approaches, like oxygen scavenging and antimicrobial technologies associated to the production of modified films, are actually considered.

A broad classification of packaging of food can be comprised into four types: Passive, Active, Intelligent, and Smart packaging [3]. They are different solutions to serve the basic and fundamental properties of package: protect, preserve, and present. So far, the dominant packaging is the basic one, based on low-cost material and no interaction with the inside food. In this passive packaging, the traditional packaging systems are included, as the use of covering material, characterized by some inherent insulating, protective, or ease of handling qualities. Usually, the ordinary packaging is not able to preserve the food and is a source of a great quantity of waste with enormous damage to the environment. This situation is increasing in consideration of the growing of consumers in emerging countries, where these consequences are not adequately considered. The packaging is considered active, when the package can interact in same way and/or react to various stimuli, in order to keep the internal environment favorable for the maintenance of the quality of the products. Several environmental, biotic and abiotic factors must be considered, in order to face positively the degradation process. The involved activity could be the presence of oxygen scavenger (an oxygen scavenger can absorb high-energy oxygen inside a package and therefore increase the shelf life of product) or anti-ROS (scavenger of radicals by oxygen or other origins) activity. Smart packaging relies on the use of chemicals, electrical, electronic or mechanical technology or any combinations of them. In particular, smart packaging involves the use of technology that adds feature such that packaging becomes an irreplaceable part of the whole product. According to what above reported, interest in the use of active and intelligent packaging systems for agricultural fresh products has increased in recent years. Active packaging refers to the incorporation of additives into packaging systems, with the aim of maintaining or extending fresh vegetable or livestock products quality and shelf life, while intelligent packaging systems are those that monitor the condition of packaged foods to give information regarding the quality of the packaged food during transport and storage [4].

Besides, the development of intelligent packaging system through the use of sensor technologies indicators (including integrity, freshness, and time-temperature indicators (TTI)) and radio frequency identification (RFID) has been evaluated for potential use in meat and meat products.

The active and smart packaging performs additional functions to the basic one and can be supported by intelligent packaging solutions. Intelligent packaging refers to the introduction of innovations in the design of packaging, with conveniences for the user and usefulness for the consumer or firms in the supply chain. In this way, the product can respond to stimuli generated by the environment or from the product being packaged. It reflects the change in a manner that makes the product more available, more useful, and more long life [5–7].

3. Reduce food waste by retaining integrity and preventing food spoilage

A large quantity of food is lost or wasted throughout the supply chain, from initial agricultural production down to final household consumption. It has been estimated that as much as half of all food grown is lost or wasted before and after it reaches the consumer [8]. That refers to the high perishable food as fresh fruit and vegetables (FFVs) and livestock products. Approximately one-third of all FFVs produced worldwide are lost along food supply chain (FSC) production [9]. High loss rates are associated with a lack of packing houses in India, with FFVs generally packed in the field and some even transported without transit packaging [10]. Food waste occurs at different points in the FSC. Market evolution in reducing waste has enormous potential to develop FSC infrastructure and reduce waste in developing and BRIC (this grouping acronym refers to the countries of Brazil, Russia, India, and China), considering some differences. Significant losses occur even early in the food supply chains in the industrialized regions and the last step of selling. On the other side, in low-income countries, food is lost mostly during the early and middle stages of the food supply chain due to deterioration; much less food is wasted at the consumer level. It is important to consider that many countries of Africa were totally auto-sufficient in food productions and limited but efficient distribution. Nowadays, food is not anymore sufficient in several parts of Africa, generating massive migrations of humans toward Europe as never reported in history records. Among the possible causes there is wrong utilization of technology's opportunities.

4. The microorganisms attack

The quality of food is a complex argument. Nowadays food is the final step of a complex series of events, changing radically the nature of the starting material. The ordinary consumers cannot acquire the quality of most of the food available, but it is the most important element of food. Most of the available food cannot be consumed directly after the production and therefore needs a form of maintenance. During the packaging, the storage, and the shelf life, food is subjected to the attack of microorganisms. These microorganisms are programmed to demolish progressively the molecular structure of the food, as soon and as completely as possible. It is only a matter of time, every structure once living is subjected to be destroyed and converted to be reutilized into a new molecular vivant structure. Food is only the intermediate step between the different forms of life. In other words, the good food is in completion with its recycling, and, working on this limbo, we can be able to efficiently utilize the food, when it is still available. The intermediate step must help to be more efficient than the molecular demolition generated by bacteria. Therefore, in preserving the food, we are working in a thermodynamically unfavorable situation. This usually means cost for low temperature or for disinfection or other methods to retard the bacterial attack. To the biotic factors, we must add the abiotic factors such as humidity and oxygen present in the air. The preserving solution mainly consists of the use of plastic packaging. Once again the solution is not sustainable and terrible in the long-term consequences. As a matter of fact, plastic is covering our planet and causing immense damages to any type of environment. On the other side, low temperature and other forced environmental conditions means a relevant need of energy and consequent considerable cost.

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The traditional concept of packaging, in sense of material projected to protect food from physical, chemical, and biological risks, can be overcome. The modified atmosphere or vacuum has led to the diffusion of 'active packaging', systems capable of interacting dynamically with the food and/or with the atmosphere in order to save the healthiness of the product and extend its shelf life. New attempts of solutions are starting from the concept of intelligent and interactive packaging. Once again, nowadays the cost of these types of packaging are not competitive, but the next future will ask for these solutions as necessary and indispensable [11].

5. The after production and food maintaining

Therefore, loss of food derived by contamination of food and spoilage by microorganisms is a major concern to food industries, involving directly consumers and indirectly government authorities. The reduction of these losses is recognized as an important component of improved food security [12]. In developing and emerging economies, this would require market-led large-scale investment in agricultural infrastructure, technological skills and knowledge, storage, transport, and distribution in order to reduce food waste in terms of food losses (decrease in food quantity) and of food spoilage (decrease in food quality), as well of food safety (spread of food-borne diseases).

The technologies used to increase the storage time and to ensure the safe consumption of highly perishable products, such as meat, have undergone a continuous evolution over the time [13–15]. Besides, the diffusion of active packaging, systems capable of interacting dynamically with the food and/or with the atmosphere in order to save the healthiness of the product and to extend its shelf life, is increasing [16]. The need to use materials, more sustainable and more compatible with food, creates a new market and leads to an intense research of natural substances usable for the production of biodegradable wrapping and edible coatings.

The effectiveness of these systems has been improved by the use of film activated by antibacterial substances and chemical or natural preservatives slow release. In recent years, interest in the production and use of active, as well as intelligent packaging systems for meat and meat products, has increased [17, 18]. Also the incorporation of natural antimicrobial substances into edible films has attracted great interest as alternative to control or reducing the growth of food-borne and spoilage microorganisms [19]. Higher consumer acceptance and the economically viable packaging systems are necessary to realize of these packaging technologies. The effectiveness of these systems was improved with the use of antibacterial substances to activate films using chemical or natural preservatives slow release. The shelf life and the safety of foods, especially those processed, are increased by antimicrobial packaging (AP) active against spoilage microorganisms and/or pathogens [20, 21].

The technologies used to increase the storage time and to ensure the safe consumption of highly perishable products are in continuous evolution over the time, in response to the needs of consumers and industry, and availability of new solutions based on advancement in scientific knowledge and technological advancements.

It needs to consider some limitations and cautions in the use of antimicrobials for meat preservation including inactivation of compounds on contact with the meat surface or dispersion of compounds from the surface into the meat mass. There are several mechanisms concerning this aspect, including incorporation of bactericidal compounds into meat products, resulting into their partial alteration by muscle components known to affect significantly the efficacy of the antimicrobial substances and their release. Therefore, physicochemical characteristics of muscle could alter the activity of antimicrobials. Furthermore, water activity of the meat could influence the antimicrobial activity and chemical stability of incorporated active substances.

When organoleptic changes occur and makes muscle foods unacceptable to the consumer, meat loss quality is considered spoiled. Contamination by microorganisms is of the main causes for organoleptic spoilage. Food package contributes to an easier distribution and protects food from environmental conditions, such as light, oxygen, moisture, microorganisms, mechanical injuries, and dust. Through the application of active packaging systems, these conditions can be regulated in several ways and, depending on the requirements of the packaged food, food deterioration can be significantly reduced.

Antimicrobial packaging (AP) is a type of active packaging and represents a promising solution, especially tailored to improve safety and to delay spoilage. Antimicrobials can be coated, incorporated, immobilized, or surface modified onto package materials. The AP development is limited, due to availability of antimicrobials and new polymer materials, regulatory concerns, and appropriate testing methods. Future work must focus on the use of biologically active derived antimicrobial compounds bound to polymers. The need for new antimicrobials with wide spectrum of activity and low toxicity will increase [22].

Plant-derived extracts (PDE) represent good candidates for antimicrobial packaging. It is possible that research and development of 'intelligent' or 'smart' antimicrobial packages will follow. These will be materials that sense the presence of microorganism in the food, triggering antimicrobial mechanisms, as a response in a controlled manner. Success of AP technologies for food applications is related to participation and collaboration of research institutions, industry, and government regulatory agencies.

The need to use materials more sustainable and more compatible with food represents a new market and leads to an intense activity in the study of natural substances for the production of biodegradable wrapping and edible coatings. The exploration of plant-derived antimicrobials should be an innovative way to find new alternative substances for food preservation via active packaging. Furthermore, the use of natural antimicrobial products derived from plant is important because they are tolerable for the consumer. The exploration of plant-derived antimicrobials represents an innovative way to find new alternative substances as food preservatives for active packaging [23].

The idea is that the exploration of PDE as preservatives can provide an innovative way to find new alternative substances for meat preservation. The use of PDE as antimicrobial has been already reported and is important since they represent a lower perceived risk to the consumer as well consumer's demand for minimally processed, preservative free products increases. To be suitable, the antimicrobial PDE should be cheap, ecologically acceptable, and target tailored, besides being effective [24, 25].

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The International Life Sciences Institute-Europe produced a comprehensive document on the use of plant materials in food products [26]. The report stresses that the ingredient for use in food products must be well identified and characterized. Accurately identification of the starting material needs in order to ensure that the plant materials for food use are consistent with respect to quality and quantity of active ingredient. The method of preparation must meet good manufacturing practices. Antimicrobial preservative releasers (films) of organic acids, as sorbic acid, silver zeolite, spice and herb extracts, allylisothiocyanate, enzymes, for example, lysozyme and bacteriocins are used for growth inhibition of spoilage and pathogenic bacteria.

6. New packaging technologies and the development of food packaging materials and nanotechnologies with food/feed applications

With the aim of development of active and passive materials for the use in the design of packages, coatings, and packaging technologies that help maintain and improve the sensorial and nutritional characteristics and safety of foodstuffs, as well as to increase their shelf life, nanofabrication technologies are emerging as valuable solutions. In this way, nanostructures and encapsulations for food applications, based on renewable materials, either edible or inedible, can be obtained, which possess active and bioactive properties to improve and develop preservation and packaging processes of foods and/or their ingredients.

Edible films are defined as a layer of material, which can be also eaten, yet provides a barrier to moisture, oxygen, and solute movement for the food [27]. If the films are not eaten, they could become biodegradable in the environment.

In recent years, the interest in microbial extracellular polysaccharides has increased, as they are candidates for many commercial applications in different industrial sector like food and pharmaceuticals. Esopolysaccharides are natural, non-toxic, and biodegradable polymers that, besides the interest on their application in the health and biotechnology, are used as stabilizers, gelling agents, and thickeners in food and cosmetic industries. Synthesis of value-added biochemical from biomass using microorganism are a promising alternative. Microbial extracellular polysaccharides cannot find its proper place in the market, unless it can be produced economically.

The microorganisms producing EPS are mainly bacteria belonging to the species *Xanthomonas*, *Leuconostoc*, *Sphingomonas*, *Alcaligenes,* and many other, which produce xanthan dextran, gelling, and curdling, all known to have industrial applications. However, when compared with the synthetic polymers, microbial EPS represent a small sector in the market because of their costly production processes [28–30]. This could be avoided by developing cost-effective and environmentally friendly production processes, such as investigating the potential use of cheaper fermentation substrates as agro-industrial and agricultural by-products and waste contributing also to reduce their environmental concern as, for instance, Olive Mill Wastewater and Pomace in the Mediterranean area [31]. Proper pre-treatment for both substrata have been developed to eliminate undesirable constituents with antimicrobial activity as phenols in oil mill water [32–34].

The fungus *Aureobasidium pullulans* produces pullulan, an extracellular and neutral polysaccharide, that is, a linear polymer mainly consisting of malt triose units interconnected to each other by α-(1,6)-glycoside bonds. This confers a good solubility in water [35]. Pullulan is listed as Existing Food Additives. The Japan Food Chemical Research Foundation and the Joint Food and Agriculture Organization/World Health Organization Expert Committee on Food Additives (JECFA) approved it as Generally Recognized as Safe (GRAS, E1204) in 2002 [36].

The incorporation of natural antimicrobial substances into edible films is of big concern in recent years because it can enhance the safety and quality of food products by controlling or reducing the growth of food-borne and spoilage microorganisms.

7. Molecular biology key role

Among the molecular biology techniques, PCR and multiplex PCR of DNA are very useful to specifically identify and detect cells of microorganisms affecting food quality, but they are not able to distinguish live from dead cells. The use of PMA™ dye is a valid alternative method to assess bacterial growth or its inhibition instead of the colorimetric methods using a tetrazolium salt [37, 38]. Furthermore, tetrazolium salts are not suitable to assess the growth of microaerophilic bacteria [39]. Other techniques as real-time polymerase chain reaction (qPCR) could also be used, but their uses imply equipment which cost is 10-fold higher than that of a thermal cycler and higher specialized knowledge to perfect protocols for its use. Instead, PCR and multiplex PCR are cheaper, less time consuming, and the results are easily readable in comparison with qPCR and microbiological methods. All that let to perform rapid and efficacious massive screening of samples as well as safety control survey. In addition, molecular biology techniques let correct species and strain identification within mixed microbial populations associated to foods and develops databases for the food source assignment of microbes.

They let to detect food-borne microbes and assess the risk they represent, comprising of viable or infectious agents in non-cultivable states, too.

However, thanks to the metagenomics technology, nowadays research focus on the whole food-associated microbial populations. They are studied at different taxonomic levels. Food microbiota is revealed with rRNA amplicon-based high-throughput sequencing approaches for food quality screening, monitoring population dynamics and meta-analyses based on food microbiota interactive databases. This allows investigating the different groups of food-associated microorganisms, mainly pathogens, spoilers, and fermentation player, as well as their interactions and influence on food quality.

8. The neem opportunity

In recent years, a major concern emerges in the field of bacterial infections to stimulate the development of innovative molecules with antimicrobial activity. Nowadays, zoonotic food- and water-borne pathogens are becoming more resistant to antibiotics. Many resistant strains have been isolated from food and could be entering the human gastrointestinal tract on an almost daily basis. The increasing incidence of food-borne diseases, coupled with the resultant social and economic implications, causes a constant striving to produce safer feed and food as to develop new natural antimicrobial agents. Plants and their agro-industrial waste and by-products represent sources of biologically active substances as potential antibiotics. According to World Health Organization [24], medicinal plants would be the best source to obtain a variety of useful drugs. Many plants produce secondary metabolites, which act against wound-contaminating bacteria and parasites [40].

Nowadays, among the most promising emerging species, Neem (*Azadirachta indica* A. Juss) is considered an effective source of environmentally powerful natural products. It is believed to be one of the most promising trees of the twenty-first century for its great potential in pest management, environmental protection, and medicine. US EPA tested biocidal efficacy and absence of environmental negative impact of neem products [41]. Among the many products obtained from the tree, neem oil (NO) is the most commercially relevant (www.organic-neem.com/why_parker_neem.html). NO is obtained by mechanical extraction of the kernels. Actually, NO is mainly utilized as natural insecticide, whereas the resulting residue, known as neem cake (NC), is used in agriculture as fertilizer or as animal feed. NCE (Neem Cake Extract) was a selected model, due to its low cost and the antimicrobial potentiality of neem, for exploring antibacterial with a view to mass treatment of meat products. NO shows strong antimicrobial activity against different microbial populations from food (spoilage microorganism and food-borne pathogens) and wound-contaminating bacteria [42–51]. The low cost and the available quantity of NC make it a potentially important raw material for developing new eco-friendly insecticidal products [52–61].

An important aspect concerns the variability of neem products, whose chemical composition must be determined. The metabolome determination of neem products was obtained using high performance thin-layer chromatography (HPTLC). HPTLC, the last evolution of planar chromatography, allows one to detect the majority of the constituents of an extract in an identifying track, named the fingerprint. An application of the HPTLC fingerprint method was developed as specific application to determine the identification of composition of utilized plants as complex extracts and their qualitative and quantitative pattern, in order to maintain the correspondence between composition and activity. It is necessary to standardize natural products, in order to establish the scientific evidences of their security and biological activity. In fact, the metabolomics approach allows obtaining the widest possible coverage, in terms of the type and number of analyzed compounds. The fingerprint by HPTLC method was successfully used to determine the herbal composition of neem studied product [62–69], evidencing the complexity in composition and the multiplicity of activities.

The antibacterial activity of neem products is known to be mainly focused on the antimicrobial properties of azadirachtin A. However, azadirachtins are the main constituents in neem oil and salannin is predominant in neem cake. The study on the metabolomic and biological activity of neem products allow us to understand the importance to handle the whole phytocomplex. Based on NO antibacterial activity, it should have several field relating human and animal health and wellbeing as well as feed and food preservation.

9. Conclusions

New packaging technologies and the development of food packaging materials and nanotechnologies with food/feed applications are an important front to produce food in a way that ensure it is used more efficiently and equitably, to reduce emerging/developed-country food waste, energy cost along FSC, the environment impact of agricultural, and agro-industrial products along FSC. Main objectives to be pursued are the development of innovative solutions in food packaging for sustainable production processes and innovative packaging systems 'green label' by the use of biodegradable and recyclable films with properties for containing antimicrobials to control the microbial contamination and food spoilage by PDE as new preservatives and food contaminant.

New promising methods can be also considered for the utilization of organic biodegradable innovative materials, like chitosan, fern, algae, and others, in order to avoid the utilization of metals, that is, silver or gold, and limit the use of pollutant plastics in the inclusion in the texture [70–78]. After the results obtained on the antimicrobial activity of NO and NCE, further researches are in progress to develop smart packaging by nanotechnology microencapsulation, as already obtained for insecticidal activity [79–81].

Author details

Marcello Nicoletti[1] and Paola Del Serrone[2]*

*Address all correspondence to: paola.delserrone@cra.it

1 Department of Environmental Biology, Sapienza University of Rome, Rome, Italy

2 Council of Agricultural Research and Economics (CREA), Zootechnics and Aquaculture Research Center, Monterotondo, Italy

References

[1] European Commission. Agriculture, Forestry and Fisheries Statistics. Luxembourg: Publications Office of the European Union; 2013. 249 pp. DOI: 10.2785/45595

[2] FAO. Mapping supply and demand for animal-source foods to 2030. In: Robinson TP, Pozzi F, editors. Animal Production and Health Working Paper No. 2. Rome; 2011. 141 pp

[3] Brockgreitens J, Abbas A. Responsive food packaging: Recent progress and technological prospects. Comprehensive Reviews in Food Science and Food Safety. 2016;**5**:3-115. DOI: 10.1111/1541-4337.12174

[4] Lee SY, Lee SJ, Choi DS, Hur SJ. Current topics in active and intelligent food packaging for preservation of fresh foods. Journal of the Science of Food and Agriculture. 2015;**95**(14):2799-810. DOI: 10.1002/jsfa.7218

[5] Vera P, Echegoyen Y, Canellas E, Nerín C, Palomo M, Madrid Y, Cámara C. Nano selenium as antioxidant agent in a multilayer food packaging material. Analytical and Bioanalytical Chemistry. 2016;**408**(24):6659

[6] Otoni CG, Espitia PJP, Avena-Bustillos RJ, McHugh TH. Trends in antimicrobial food packaging systems: Emitting sachets and absorbent pads. Food Research International. 2016;**83**:60

[7] Kim JU, Ghafoor K, Ahn J, Shin S, Lee SH, Shahbaz H M, Shin H-H, Kim S, Park J. Kinetic modelling and characterization of a diffusion-based time-temperature indicator (TTI) for monitoring microbial quality of non-pasteurized angelica juice. LWT—Food Science and Technology. 2016;**67**:143

[8] Lundqvist J, de Fraiture C, Molden D. Saving water: From field to fork-curbing losses and wastage in the food chain. In: SIWI Policy Brief. Stockholm, Sweden: SIWI; 2008

[9] Kader AA. Increasing food availability by reducing postharvest losses of fresh produce. Acta Horticulturae. 2005;**682**:2169-2175

[10] Choudhury ML. Recent developments in reducing post-harvest losses in the Asia-Pacific region. In: Rolle RS, editor. Reports of the APO Seminar on Reduction of Postharvest Losses of Fruit and Vegetables; October 2004. Tokyo, Japan: FAO, Asian Productivity Organization (APO); 2006. pp. 5-11

[11] HLPE. Food losses and waste in the context of sustainable food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. Rome; 2014. www.fao.org/cfs/cfs-hlpe

[12] Nellemann C et al, editors. The Environmental Food Crisis. Kenya: United Nations Environment Programme, Nairobi; 2009

[13] Meat Industry Service. Natural Antimicrobials, Parasitic Bacteria and Bacteriophages; 2006. http://www.meatupdate.csiro.au/new/Natural%20Antimicrobials,%20Parasitic%2Bacteria%20and%20Bacteriophages.pdf [Accessed: 19 December 2014]

[14] Maruchecka A, Greis N, Menac C, Cai L. Product safety and security in the global supply chain: Issues, challenges and research opportunities. Journal of Operations Management. 2011;**29**:707-720. DOI: 10.1016/j.jom.2011.06.007

[15] Thakur MS, Ragavan KV. Biosensors in food processing. Journal of Food Science and Technology. 2013;**50**(4):625-641. DOI: 10.1007/s13197-012-0783-z

[16] Singh RK, Singh N. Quality of packaged foods. In: Han JH, editor, Innovations in Food Packaging. Amsterdam: Elsevier Academic Press; 2005. pp. 22-24

[17] De Kruijf N, Van Beest M, Rijk R, Sipiläinen-Malm T, Paseiro Losada P, De Meulenaer B. Active and intelligent packaging: Applications and regulatory aspects. Food Additives & Contaminants. 2002;**19**:144-162

[18] Kerry JP, O'Grady MN, Hogan SA. Past, current and potential utilization of active and intelligent packaging systems for meat and muscle-based products: A review. Meat Science. 2006;**74**:113-130

[19] Cooksey K. Effectiveness of antimicrobial food packaging materials. Food Additives & Contaminants. 2005;**22**:980-987

[20] Ozdemir M, Floros JD. Active food packaging technologies. Critical Reviews: Food Science and Nutrition. 2004;**44**(3):185-193

[21] Coma V. Bioactive packaging technologies for extended shelf life of meat-based products. Meat Sci. 2008;**78**:90-103.

[22] Malhotra B, Keshwani A, Kharkwa H. Antimicrobial food packaging: Potential and pitfalls. Frontiers in Microbiology. 2015;**6**:611. DOI: 10.3389/fmicb.2015.00611. PMCID: PMC 4468856

[23] Dobrucka R, Cierpiszewski R. Active and intelligent packaging food—Research and development—A review. Polish Journal of Food and Nutrition Sciences. 2014;**64**(1):7-15. DOI: 10.2478/v10222-012-0091-3

[24] WHO, World Health Organization. Quality Control Methods for Medicinal Plant Materials. Geneva: WHO Library Cataloguing; 2011

[25] Negi PS. Plant extracts for the control of bacterial growth: Efficacy, stability and safety issues for food application. International Journal of Food Microbiology. 2012;**156**(1):7-17. DOI: 10.1016/j.ijfoodmicro.2012.03.006

[26] Schiltera B, Anderssonb C, Antonc R, Constablea A, Kleinerd J, O'Briene J, Renwickf AG, Korverg O, Smith F, Walker I. Guidance for the safety assessment of botanicals and botanical preparations for use in food and food supplements. Food and Chemical Toxicology. 2003;**41**:1625-1649. DOI: 10.1016/S0278-6915(03)00221-7

[27] Bourtoom T. Edible films and coatings: Characteristics and properties (review article). International Food Research Journal. 2008;**15**:237-248

[28] Aguilera M, Quesada MT, Aguila VG, Morillo JA, Rivadeneyra MA, Romos-Cormenzana A, Monteoliva-Sanchez M. Characterization of *Paenibacillus jamilae* strains that produce exopolysaccharide during growth on and detoxification of olive mill wastewaters. Bioresource Technology. 2008;**99**:5640-5644

[29] Ahvenainen R. Active and intelligent packaging: An introduction. In: Ahvenainen R, editor. Novel Food Packaging Techniques. Cambridge, UK: Woodhead Publishing Ltd; 2003. pp. 5-21

[30] Appendini P, Hotchkiss JH. Review of antimicrobial food packaging. Innovative Food Science and Emerging Technologies. 2002;**3**:113-121

[31] Stasinakis SA, Elia I, Petalas AV, Halvadakis CP. Removal of total phenols from olive-mill wastewater using an agricultural by-product, Olive Pomace. Journal of Hazardous Materials. 2008;**160**(2-3):408-413. DOI: 10.1016/j.jhazmat.2008.03.012

[32] Sutherland IW. Bacterial exopolysaccharides. In: Kamerling JP, editor. Comprehensive Glycoscience. Amsterdam: Elsevier; 2007

[33] Nicolaus B, Kambourova M, Toksoy Öner E. Exopolysaccharides from extremophiles: From fundamentals to biotechnology. Environmental Technology. 2010;**31**:1145-1158

[34] Salehizadeh H, van Loosdrecht MCM. Production of polyhydroxyalkanoates by mixed culture: Recent trends and biotechnological importance. Biotechnology Advances. 2004;**22**:261-279

[35] Xiao Q, Lim, LT, Tong Q. Properties of pullulan-based blend films as affected by alginate content and relative humidity. Carbohydrate Polymers. 2012;**87**:227-234

[36] Chaen H. Pullulan. In: Imeson A, editor. Food Stabilisers. Thickeners and Gelling Agents. West Sussex, UK: Blackwell Publishing; 2010. pp. 266-274

[37] Grare M, Fontanay S, Cornil C, Finance C, Duval RE. Tetrazolium salts for MIC determination in microplates: Why? Which salt to select? How? Journal of Microbiological Methods . 2008;**75**:156-159

[38] Rahman M, Kuhn M, Rahman P, Olsson-Liljequist B, Molby R. Evaluation of a scanner-assisted. Colorimetric MIC method for susceptibility testing of Gram-negative fermentative bacteria. Applied and Environmental Microbiology. 2004;**70**:2398-2403

[39] Klančnik A, Piskernik S, Jeršek B, Smole MS. Evaluation of diffusion and dilution methods to determine the antibacterial activity of plant extracts. Journal of Microbiological Methods. 2010;**81**:121-126

[40] Swati D, Kumar SP, Jyoti R, Renu T, Arti B. Phytochemical analysis of seeds of certain medicinal plants. International Research Journal of Pharmacy. 2014;**5**(2):102-105. DOI: 10.7897/2230-8407.050221

[41] EPA. Cold Pressed Neem Oil PC Code 02500. U.S. Environmental Protection Agency Office of Pesticide Programs. Biopesticides and Pollution Prevention Division; Washington, D.C. 2012

[42] Del Serrone P, Nicoletti M. Antimicrobial activity of a neem cake extract in a broth model meat system. International Journal of Environmental Research and Public Health. 2013;**10**:3282-3295

[43] Del Serrone P, Nicoletti M. Alternative control of muscle spoilage by a neem cake extract. Pharmacologyonline Archive. 2013;**3**:132-136

[44] Del Serrone P, Nicoletti M. Impiego di un estratto di neem cake per la conservazione della carne fresca confezionata. Igiene, Alimenti, Disinfestazione e Igiene Ambientale. 2013;**30**(4):4-8

[45] Del Serrone P, Failla S, Nicoletti M. Natural control of bacteria affecting meat quality by a neem (*Azadiracta indica* A Juss) cake extract. Natural Product Research. 2014;**29**(10):985-987. DOI: 10.1080/14786419.2014.964708

[46] Del Serrone P, Nicoletti M 2014. Evaluation of a mono-component and a multi-component herbal extracts as candidates for antimicrobial packaging of fresh retail meat. In: Cimmino S, Pezzuto M, Silvestre C, editors. Proceedings: Eco-sustainable Food

Packaging based on Polymer nanomaterials. International Conference COST ACTION FA0904; 26-28 February 2014; CNR Rome, Italy. p. 36

[47] Del Serrone P, Toniolo C, Nicoletti M. Neem (*Azadirachta indica* A. Juss) seed oil a natural preservative to control meat spoilage. Foods. 2015;4:3-14. DOI: 10.3390/foods4010003

[48] Del Serrone P, Toniolo C, Nicoletti M. Neem (*Azadirachta indica* A. Juss) seed oil to tackle enteropathogenic *Escherichia coli*. BioMed Research International. 2015;**343610**:10 pp. DOI: 10.1155/2015/343610

[49] Del Serrone P, Toniolo C, Nicoletti M. Evaluation of a three-component plant derived extract as preservative for fresh retail meat. Research & Reviews: Journal of Food Dairy Technology. 2015;**3**(3):24-31

[50] Del Serrone P, Toniolo C, Nicoletti M. Assessment of a garlic product's antibacterial activity and its effects towards enteropathogenic *Escherichia coli*. International Journal of Food Sciences and Nutrition. 2016;**1**(3):58-66

[51] Del Serrone P, Buttazzoni L, Nicoletti M. Nutrition and multiresistance alert. EC Nutrition. 2016;**4**(1):772-783

[52] Del Serrone P, De Matteis G, Rufrano D, Veneziano V, Claps S, et al. Goat wound-contaminating-bacteria restraint by neem oil. SOJ Microbiology & Infectious Diseases. 2015;**3**(2):1-10

[53] Benelli G, Nicoletti M. Shedding light on bioactivity of botanical by-products: Neem cake compounds deter oviposition of the arbovirus vector *Aedes albopictus* (Diptera: Culicidae) in the field. Parasitology Research. 2013;**110**:2013-2021

[54] Benneli G, Canale A, Toniolo C, Higuchi A, Murugan K; Pavela R, Nicoletti M. Neem (*Azadirachta indica*): Towards the ideal insecticide? Natural Product Research. 2016;1-18

[55] Benelli G, Bedini S, Cosci F, Toniolo C, Conti B, Nicoletti M. Larvicidal and ovideterrent properties of neem oil and fractions against the filariasis vector *Aedes albopictus* (Diptera: Culicidae): A bioactivity survey across production sites. Parasitology Research. 2015;**114**(1):227-236

[56] Benelli G, Murugan K, Panneerselvam C, Madhiyazhagan P, Conti B, Nicoletti M. Old ingredients for a new recipe? Neem cake, a low-cost botanical by-product in the fight against mosquito-borne diseases. Parasitology Research 2015;**114**(2):391-397. DOI: 10.1007/s00436-014-4286-x

[57] Chandramohan B, Murugan K, Madhiyazhagan P, Kovendan K, Mahesh Kumar P, Panneerselvam C, Dinesh D, Subramaniam J, Rajaganesh R, Nicoletti M, Canale A, Benelli G. Neem by-products in the fight against mosquito-borne diseases: Biotoxicity of neem cake fractions towards the rural malaria vector *Anopheles culicifacies* (Diptera: Culicidae). Asian Pacific Journal of Tropical Biomedicine. 2016;**6**(6):472-476. DOI: 10.1016/j.apjtb.2015.11.013

[58] Nicoletti M, Maccioni O, Ciocchetti T, Mariani S, Vitali F. Neem tree (*Azadirachta indica* A. Juss) as source of bioinsectides. In: Perveen F, editor. Insecticides—Advances in Integrated Pest Management; 2012. ISBN: 978-953-307-780-2. http://www.intechopen.com/articles/show/title/neem-tree-azadirachta-indica-a-juss-as-source-of-bioinsectides

[59] Nicoletti M, Serafini M, Aliboni A, Armando D'Andrea A, Mariani S. Toxic effects of neem cake extracts on *Aedes albopictus* (Skuse) larvae. Parasitology Research. 2010;**107**:89-94

[60] Nicoletti M, Murugan K, Benelli G. Chapter 11 Emerging insect-borne diseases not-involving the human health. In: Trdan S, editor. Insecticide Resistance. Rijwcka, Croatia: In-Tech; 2016. pp. 219-242

[61] Nicoletti M, Murugan K, Canale A, Benelli G. Neem-borne molecules as eco-friendly tools against vectors of economic importance. Current Organic Chemistry. 2016;**20**(25):2681-2689. DOI: 10.2174/1385272820666160218233923

[62] Nicoletti M. HPTLC fingerprint: a modern approach for the analytical determination of botanicals. Revista Brasileira de Farmacognosia. 2011;**21**(5):818-823

[63] Nicoletti M, Toniolo C. HPTLC fingerprint analysis of plant staminal cell products. Journal of Chromatography & Separation Techniques. 2012;**3**:7-11. DOI: 10.4172/2157-7064.1000148

[64] Nicoletti M, Toniolo C, Gallo FR, Multari G, Palazzino G. Traceability in multi-ingredient botanicals by HPTLC fingerprint approach. Journal of Planar Chromatography. 2013;**26**(3):243-247

[65] Nicoletti M. Phytochemical techniques in complex botanicals. The XXI Century Analytical Technique. Journal of Chromatography & Separation Techniques. 2012;**4**:186. DOI: 10.4172/2157-7064.1000186

[66] Gallo FR, Multari G, Federici E, Palazzino G, Nicoletti M, Petitto V. The modern analytical determination of Botanicals and similar novel natural products by the HPTLC Fingerprint approach. In: Rahman AU, editor. Studies in Natural Products Chemistry. Elsevier; 2012. **37**; pp. 217-258

[67] Nicoletti M, Toniolo C. Fingerprint HPTLC analysis of marketed products. Pharmacology. 2013;**3**(6):30-36

[68] Toniolo C, Nicoletti M, Maggi F, Venditti A. Determination by HPTLC of chemical composition variability in raw material used in botanicals. Natural Products Research. 2014;**28**(2):119-126

[69] Nicoletti M, Toniolo C. Analysis of multi-ingredient food supplements by fingerprint HPTLC approach. Journal of Chemistry and Chemical Engineering. 2015;**9**:239-244

[70] Anbu P, Murugan K, Madhiyazhagan P, Dinesh D, Subramaniam J, Panneerselvam C, Suresh U, Alarfaj A A, Murugan K, Munusamy A., Higuchi A, Hwang J-S, Kumar S, Nicoletti M, Benelli G. Green-synthesised nanoparticles from Melia azedarach seeds and the cyclopoid

crustacean *Cyclops vernalis*: an eco-friendly route to control the malaria vector *Anopheles stephensi*?, Nat Product Res 2016. 30:18, 2077-2084, DOI: 10.1080/14786419.2015.1114935 http://dx.doi.org/10.1080/14786419.2015.1114935

[71] Panneerselvam C, Murugan K, Roni M, Tabini A, Suresh U, Madhiyazhagan P, Subramanian J, Chandramohan B, Dinesh D, Kovendan K, Mahesh KP, Nicoletti M, Higuchi A, Kumar S, Benelli G. Fern-synthetized nanoparticles in the fight against malaria: LC/MS analysis of *Pteridium aquilium* leaf extract and biosynthesis of silver nanoparticles with high mosquicidal and antiplasmodial activity. Parasitology Research. 2016;**115**(3):997-1013. DOI: 10.1007/s00436-015-4828-x

[72] Sujitha V, Murugan K, Paulpandi M, Panneerselvam C, Suresh U, Roni M, Nicoletti M, Higuchi A, Madhiyazhagan P, Subramaniam J, Dinesh D, Vadivalagan C, Chandramohan B, Alarfaj AA, Munusamy MA, Barnard DR, Benelli G. Green-synthesized silver nanoparticles as a novel control tool against dengue virus (DEN-2) and its primary vector Aedes aegypti. Parasitology Research. 2015.**114**(9):3315-25. DOI: 10.1007/s00436-015-4556-2

[73] Murugan K, Samidoss CM, Panneerselvam C, Higuchi A, Roni M, Suresh U, Chandramohan B, Subramaniam J, Madhiyazhagan P, Dinesh D, Rajaganesh R, Alarfaj AA, Nicoletti M, Kumar S, Wei H, Canale A, Mehlhorn H, Benelli G. Seaweed-synthesized silver nanoparticles: An eco-friendly tool in the fight against *Plasmodium falciparum* and its vector *Anopheles stephensi*? Parasitology Research. 2015;**114**(11):4087-4097. DOI: 10.1007/s00436-015-4638-1

[74] Jaganathan A, Murugan K, Panneerselvam C, Madhiyazhagan P, Dinesh D, Vadivalagan C, Aziz AT, Chandramohan B, Suresh U, Rajaganesh R, Subramaniam J, Nicoletti M, Higuchi A, Alarfaj AA, Munusamy MA, Kumar S, Benelli G. Earthworm-mediated synthesis of silver nanoparticles: A potent tool against hepatocellular carcinoma, *Plasmodium falciparum* parasites and malaria mosquitoes. Parasitology Research. 2016;**65**(3):276-284. DOI: 10.1016/j.parint.2016.02.003

[75] Muruga K, Panneerselvam C, Subramaniam J, Madhiyazhagan P, Hwang J-S, Wang L, Dinesh D, Suresh U, Roni M, Higuchi A, Nicoletti M, Benelli G. Eco-friendly drugs from the marine environment: spongeweed-synthesized silver nanoparticles are highly effective on Plasmodium falciparum and its vector Anopheles stephensi, with little non-target effects on predatory copepods. Environ Sci Pollut Res 2016. **23**:16671-16685. DOI 10.1007/s11356-016-6832-9

[76] Murugan K, Aamina JM, Paarnelservam C, Dinesh D, Suresh U, Subrapamanian Madhiyazaghan P, Hwang JS, Wang L, Nicoletti M, Benelli G. *Aristolochia indica* green-synthesized silver nanoparticles: a sustainable control tool against the malaria vector *Anopheles stephensi*? Research in Veterinary Science. 2015;**102**:127-135

[77] Amerasan D, Natarej T, Murugan K, Madhiyazhadan P, Panneerselvan C, Nicoletti M, Benelli G. Myco-synthesis of silver nanoparticles using *Metarhizium anisopliae* against the rural malaria vector *Anopheles culicifacies* Giles. Journal of Pest Science. 2015;**9**(1):249-256. DOI: 10.1007/s10340-0.15-0675-x

[78] Benelli G. Plant-mediated synthesis of nanoparticles: A newer and safer tool against mosquito-borne diseases? Asian Pacific Journal of Tropical Biomedicine. 2016;**6**(4):353-354

[79] Chandramohan B, Murugan K, Panneerselvam C, Madhiyazhagan P, Chandirasekar R, Dinesh D, Kumar PM, Kovendan K, Suresh U, Subramaniam J, Rajaganesh R, Aziz AT, Syuhei B, Alsalhi MS, Devanesan S, Nicoletti M, Wei H, Benelli G. Characterization and mosquitocidal potential of neem cake-synthesized silver nanoparticles: Genotoxicity and impact on predation efficiency of mosquito natural enemies. Parasitology Research. 2016;**115**(3):1015-25. DOI: 10.1007/s00436-015-4829-9

[80] Vijayan V, Aafreen S, Sakthivel S, Reddy RK. Formulation and characterisation of solid lipid nanoparticles loaded neem oil for topical treatment of acne. Journal of Acute Disease. 2013;**2**(4):282-286. DOI:10.1016/S2221-6189(13)60144-4

[81] Rajendran R, Radhai R, Balakumar C, Ahamed HAM, Vigneswaran C, Vaideki K. Synthesis and characterization of neem chitosan nanocomposites for development of antimicrobial cotton textiles. Journal of Engineered Fibers and Fabrics. 2012;**7**(1):136-141

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