2nd CIRCUL-A-BILITY CONFERENCE

BOOK OF ABSTRACTS

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COST Action 191249 Re-Thinking Packaging for Circular & Sustainable Food Supply Chains of the Future

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HOW TO ASSESS THE ENVIRONMENTAL SUSTAINABILITY OF FOOD PACKAGING? A NEW APPLICATION TOOL

Vermeulen An, Brecht Van Der Hoeven, Peter Ragaert, Lieselot Boone, Jo Dewulf

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Many food and packaging companies are confronted with questions on how to choose the most environmentally sustainable food packaging. Within this study, a decision support system (DSS) was developed that supports companies to make an informed decision regarding the most sustainable materials for their food packaging. Therefore the whole value chain (raw material for packaging, food shelf-life and end-of-life options (i.e. impact of chemical and mechanical recycling)) were considered in the environmental sustainability evaluation by relying on life cycle assessment.

Five different food products ranging from short shelf life to long shelf life products are considered in the DSS. For each product different relevant packaging materials (paper/cardboard, plastics, biobased and/or biodegradable materials) were evaluated. Shelf life tests (microbial, chemical and sensorial tests) were performed to ensure that no extra food waste would occur by changing to an alternative packaging.

The DSS allows the user to simulate the impact results (Resource footprint CEENE), Global warning and total impact score) for the primary packaging on its own or the combined food-packaging impact (incl. food losses). The type and mass of the primary packaging and the food to be packed should be filled in by the user, next to the composition of the packaging material. Regarding the end-of-life, the user can choose between the Belgian, Benelux or EU average system. This comparison also highlights the need for a more harmonized end-of-life treatment of primary packaging materials in order to allow food companies to make their most sustainable packaging solution. Finally, the CIRCOPACK tool will also allow the comparison multiple simulations, so that any difference in*

environmental impact becomes visible. This way, an informed decision can be made.

Keywords: *food packaging value chain, decision support tool, recyclability, life cycle assessment*

APPLICATION OF CIRCULARITY MICRO-INDICATORS TO PLASTIC FOOD PACKAGING

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The difficulty in combining sustainable polymeric options with the requirements to guarantee food quality and food safety, has impeded the transition to a more circular economy in the food packaging sector, although efforts have been made in recent years to redesign plastic packaging to consider its sustainability. The limitations imposed by both the legislation and the market also has prevented this transition because several recycled, bio-based, biodegradable, or compostable polymeric materials are not allowed to enter in contact with food and the price of the polymeric sustainable materials allowed are considerably more expensive than alternative virgin polymers. In addition, polymers being one of the most viable solutions for protecting food quality, keeping food fresh, and increasing its shelf life, are lightweight, inexpensive, and have properties that are difficult to replicate with other materials. Therefore, the solution for the transition towards more sustainable food packaging is not to ban the use of polymeric materials or to replace them with less sustainable and less circular materials, but to rethink the way in which they are used and especially how to manage them at the end-of-life, to cause the least possible environmental impact. One of the means to improve the sustainable use of plastics is by looking at their circularity. To assess circularity there is no standard method, and the scientific community has proposed a myriad of tools for this purpose, such as circularity micro-indicators. However, circularity micro-indicators range widely in complexity, philosophy, method of calculation, and type of required information, and most focus only on some aspects of the entire product life cycle.

In this paper, we analyse the different circularity indicators proposed in the literature that could typically be applied to food packaging, in the scope of plastic materials. For each micro-indicator, we discuss and argue its potential

application in this industrial sector, and we highlight the most relevant indicators overall for that sector. This is done obviously in a broad sense, as specific products can sometimes fall outside the typical characteristics and features of food packaging applications. In addition, we analyse other factors that influence the calculation of the micro-indicators identified for food packaging. Finally, we propose a holistic set of micro-indicators that together provide a fair assessment of circularity of plastic food packaging.

Keywords: *circular economy, circularity indicators, sustainability, food packaging*

SHELF-LIFE INCLUSION IN FOOD PACKAGING LIFE CYCLE ASSESSMENT STUDIES: DIFFERENT MODELLING APPROACHES

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Long seen as an additional environmental burden, food packaging has recently been redeemed as a beneficial player in food-packaging environmental assessments due to its properties related to food protection and convenience. Shelf-life inclusion in food packaging Life Cycle Assessment (LCA) is an effective strategy for thoroughly evaluating the sustainability of food-packaging systems. Following eco-design principles, all properties of food packaging must be considered to provide a full picture of its sustainability. Shelf-life permits account for the so-called indirect environmental effects of food packaging solutions, known in the literature as the ability to reduce the probability of food waste at different levels. However, the direct inclusion of such performances into LCA studies is not common practice nor is harmonized among practitioners. Among the recent food-packaging LCA that consider shelf-life effects on environmental results, different functional units have been proposed. Shelf-life could either be expressed as an inherent characteristic of the food-packaging system or as a pre-defined timespan. With the greater scope to foster the development of holistic eco-design approaches for the food packaging field and harmonization in the field, it is believed that further research on Functional Unit selection for unequivocal shelf-life inclusion in food-packaging LCA is of critical importance. The case of packaged red fruits was implemented to investigate the methodological consequences of different functional unit definitions for shelf-life inclusion on the results of comparative LCA studies. Different packaging solutions for red fruits, including Modified Atmosphere Packaging (MAP) solutions, were compared. Two functional units, respectively based on the two current approaches, were implemented in the study. The study was carried out following the requirements of ISO 14040:2021 and ISO 14044:2021 standards. System modelling was performed thanks to SimaPro v 9.3.0.2

software and Ecoinvent v 3.8 database (cut-off allocation criteria). ReCiPe 2016 v1.1 midpoint, H/A methodology was used for impacts assessment. Results showed that the two defined functional units lead to different modelling choices and characterization results. The hot-spot analysis identified food production, which included the increased mass due to food waste probabilities, as the main responsible for environmental impacts in both approaches. Nevertheless, in characterization results, when shelf-life was expressed as an inherent property of the systems, the overall best solution was the one that successfully balanced food protection performances and packaging materials' use and disposal. Such approach could be useful for strategic decision-making processes in screening multiple packaging solutions by also providing useful insights. On the opposite, when a pre-defined timespan was given, the system that most efficiently fulfills the requested performance, showed the best environmental profile. This latter approach should be implemented when strategic logistic choices must be met as it permits to differentiate packaging solutions based on their ability to fulfill such requirements. Eventually, this study provides suggestions to foster eco-design principles in the food packaging field and paves the way towards harmonization of methodological approaches for food packaging LCA studies.

Keywords: *LCA, eco-design, food packaging, shelf-life, functional unit*

THE IMPACT ON RECYCLABLE PACKAGING CONCEPTS FOR CHICKEN BREAST FILETS – IN TERMS OF SHELF LIFE, POTENTIAL FOOD WASTE AND CONSUMER PERSPECTIVES

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There is an increased focus on circular economy and the United Nations (UN) sustainable goal 12 "Responsible production and consumption" focuses both on the reduction of food waste (Target 12.3), and the reduction of waste through e.g., recycling and reuse (Target 12.5). The European Union has identified plastic as a key priority in the circular economy and defined ambitious recycling targets. This imposes pressure on stakeholders for implementing more recyclable food packaging materials. Design for recycling is a strategy to increase recycling of plastic materials, which often includes the selection of monomaterials as replacement for complex and multi-layered materials. However, monomaterials may result in reduced barrier properties which in turn could imply shorter shelf life, contrary to that long shelf life is often regarded as important in order to prevent/reduce and lead to increased food waste. This trade-off must be taken into consideration. Furthermore, significant attention has been put on the packaging in general and on plastic in particular over the last years. Consumer awareness of the environmental threat caused by plastic materials going astray has increased. As a result, consumer behaviour has evolved towards higher avoidance of plastic packaging as well as higher demand for recyclable materials.

The primary function of the packaging is to protect and preserve the food. However, aiming for sustainable development requires paying attention to all these aspects; endeavour to obtain an optimal shelf life and prevent food waste, reduction of plastic consumption and pollution by increased recycling,

and meeting consumer needs in terms of packaging functionality, practicality and price.

This research has been conducted in the ReducePack project, with the aim to achieve a reduced plastic consumption (without increased food waste) by three strategies; "reduce by replacing", "reduce by recycling", "reduce by reducing". The present talk will focus on different aspects that have been investigated related to new packaging concepts for food; in particular, the effect of recyclable monomaterials as replacement of non-recyclable materials on the shelf life of chicken filets. Furthermore, results from consumer studies conducted online (N= 323) and in supermarkets (N= 60) will be reported. The studies investigated consumer choices and compromises between shelf life (date labels) and plastic use (ordinary versus reduced and/or recyclable plastic) for chicken breast filets. Findings reveal that 50% of the online respondents defined 0-4 days as a sufficient shelf life when purchasing chicken filets. This lower shelf-life acceptance was confirmed in the supermarket interviews, where the sample presenting four days of shelf life with reduced and recyclable plastic was selected 2.3 times more frequently than the sample presenting eight days of shelf life with regular packaging. Additionally, over 50% of the online respondents stated being willing to pay an identical or higher price for chicken filets with three days shorter shelf life and packaging with reduced plastic use, compared to today's packaging.

This study describes and points out the complexity of food packaging and sustainable development.

Keyword: *recyclability, consumer, chicken, shelf life, plastic reduction*

OVERCOMING NEGATIVE EFFECTS FROM COMMUNICATION OF NON-RECYCLING INFORMATION ON PRODUCT PACKAGES

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Recycling information is not mandatory on product packages. Companies may not provide information about how packaging should be recycled for products whose packaging material is not recyclable. A plausible explanation is that provision of such information may harm their brand image. Lack of recycling information creates an additional problem for consumers who wish to recycle and may end up recycling material that is not supposed to, thus contributing to a phenomenon known as "wishful recycling". Wishful recycling may do more harm than good as it may cause contamination of recycling streams, machinery breakdowns, and degradation of recycled materials. In this study, we show that the provision of information that packaging material of products is not recyclable does harm consumer purchase intentions and product evaluations (Study 1). We further demonstrate that social norms could mitigate this effect (Study 2) by improving product evaluations which have downstream consequences on consumer purchase intentions. We discuss implications for research and managerial practice.

Keywords: *packaging recycling, wishful recycling, social norms, consumer response*

DESIGNING SUSTAINABLE PACKAGING MATERIALS FOR CURED MEAT PRODUCTS

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Packaged cured meat products are very sensitive to microbial growth, fat oxidation, and discoloration, especially caused by residual oxygen and water vapour concentration in the headspace of the package. Therefore, packaging plays a crucial role in preventing chemical, enzymatical and physical spoilage thanks to barrier properties effective for humidity, gases (O^2, CO^2, odours), and UV radiation.

The most widely used packaging materials for cured meat products are plastics, including polyethylene terephthalate (PET) together with multi-layered packaging composed mainly of polyethylene (PE) and ethylene-vinyl-alcohol (EVOH). Plastic materials, characterized by a low cost and lightweight, have also excellent processing performances such as mechanical strength, low permeability, transparency, and heat sealability. However, these plastic materials are not environmentally sustainable as they are assembled with non-renewable sources (fossil fuels and natural gas), moreover, they are not biodegradable or compostable and the recycling process is still an open problem due to challenges with layers separation.

In this context, thanks to the recent environmental policies and the growing public awareness of consumers on the environmental challenges, there is an urgent need to identify suitable and effective bio-based packaging materials, which can ensure high food quality and safety as conventional packaging materials provide. Potential solutions could be mono plastic materials and bio-based plastics, which are both fully recycled and bio-based and compostable materials such as bioplastics (PLA, PHA, PBS). However, to our knowledge, only a few scientific papers are available regarding sustainable packaging for cured meat products in modified protective atmosphere (MAP) conditions, and up to

now, in the market, the most sustainable packaging solutions are limited to paper assembled with plastic layers.

The aim of this research is to identify and study innovative packaging materials designed for cured meat products in MAP, with a higher degree of sustainability and circularity degree. Therefore, sustainable and innovative packaging materials for cured meat products will be reviewed from the literature and the most suitable materials will be selected in order to investigate their mechanical and barrier properties. The materials with the best performances will be used for a shelf life study, where microbiological growth, pH and aw values, colour changes, O_2 and CO_2 concentration in the modified atmosphere headspace and sensorial evaluation will be carried out.

The obtained results will give a strong basis for further processing aspects for industrial applications of packaging materials for cured meat products.

Keywords: *sustainability, packaging, shelf life, meat, modified atmosphere*

ECO-DESIGN OF CHICKEN MEAT-PACKAGING SYSTEM

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Background: The environmental and socio-economic impacts of food waste along the agri-food supply chain are well documented in the scientific literature. Several studies have highlighted the need to incorporate the impact of food waste into the environmental impact evaluation of food-packaging systems. These studies have shown that including the food waste impact could change the life cycle assessment (LCA) results of the food-packaging system significantly. Moreover, research shows that in industrialised nations, food waste mostly occurs at the downstream end (retail and consumer) of the agri-food supply chain in contrast to the upstream end (postharvest and storage) in the developing world. A leading cause of food waste at the downstream end of the food supply chain is due to food not being sold or used before it reaches its shelf-life or use-by date. One of the primary functions of food packaging is to protect the food and thereby extend its shelf-life. Therefore, there is the need to invest in innovative and sustainable food packaging systems. However, some of these packaging innovations that help to extend the shelf-life of the food and prevent waste may increase the environmental impact of the food-packaging system; this impact could be significant in some cases. Nevertheless, for food products such as meat with often high food-to-packaging (FTP) environmental impact ratios, there is a justification to invest in innovative packaging solutions to prevent food waste.

Aim: The aim of this study is to assess and improve the environmental performance of chicken meat-packaging system using eco-design principles.

Methods: LCA (ISO 14040, 14044: 2006) was used to assess the environmental impact of two conventional chicken meat packaging per kg of chicken meat

from cradle-to-gate of the meat processing plant. Ten impact categories will be evaluated including climate change, eutrophication, and toxicological-related impacts. Also, different end-of-life waste management scenarios for both food waste and packaging will be included in the assessment. Finally, to reduce the food waste rate and improve the environmental performance of the chicken meat-packaging system, eco-design principles, such as available in ISO 14006:2020, will be incorporated into the evaluation based on the LCA results obtained.

Results and Discussion: The preliminary results of this study indicate that the contribution of the packaging to the chicken meat-packaging system in the climate change impact category was not relatively significant (0.4 – 4.7%). However, other studies have indicated that the impact could be significant in other impact categories. Therefore, there is a justification to broaden the impact assessment into other impact categories.

Conclusion: The environmental impact of two conventional chicken meat packaging was assessed. Further assessment will be done to include other impact categories. Recommendations to reduce food waste and packaging impacts will be presented and discussed.

Keywords: *life cycle assessment, eco-design, food waste, food packaging, chicken meat*

INTENTION TO PURCHASE ACTIVE AND INTELLIGENT PACKAGING TO REDUCE HOUSEHOLD FOOD WASTE: EVIDENCE FROM ITALIAN CONSUMERS

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Food packaging innovations, such as active and intelligent ones, improve food safety and lower household food waste (FW) by extending product shelf-life and providing information about food quality, respectively. In detail, active packaging refers to the incorporation of several substances, directly into the packaging material or in a separate container (e.g., sachet, label) inside the package, which can absorb (scavenger) or release (emitter) gaseous matter. Instead, intelligent packaging is a system able to monitor the condition of packaged food, or the environment surrounding the food, providing the user the information about its freshness. Therefore, these technologies could help in minimizing household waste, extending food shelf-life, or reducing the risk of throwing away foods that are still edible. The consumer adoption of such innovations could contribute to reaching one of the Sustainable Development Goals which calls for halving the per capita global FW by 2030. Thus, this study aims to investigate the consumers' willingness to purchase active and intelligent packaging to reduce household FW using a sample of 260 Italian consumers and a modified Theory of Planned Behavior (TPB) model. Reviewed studies point out that not only individual attitude, subjective norm, and perceived behavioral control but also individual awareness, food shopping routines, planning routines, and ability to reuse food leftovers, are related to the individual willingness to reduce FW. According to the Authors, these factors may also be related to individual willingness to purchase active or intelligent packaging in attempting to further mitigate household waste. Results showed that individual intention to reduce household FW was a good predictor of the willingness to purchase active and intelligent packaging. However, respondents aiming to reduce their waste at home were more willing to purchase the

intelligent technological solution rather than the active one. Concerning the determinants of the intention to reduce the household FW, four out of the seven individual-related variables assessed in our conceptual models, and selected according to the literature, showed a positive and significant effect on the individual's intention to lower FW at the household level. Attitude towards FW was the strongest predictor of the intention to reduce waste at home followed by perceived behavioral control, awareness, and the ability to plan food routine. These results come with relevant policy and marketing implications. Policymakers and companies may develop informational campaigns to raise the level of consumers' knowledge about these technological solutions to encourage their acceptance and adoption among consumers. Furthermore, policies such as informational and educational campaigns should also be focused on raising awareness about the negative effects of FW among consumers, which may have an important role in supporting intentional and behavioral changes.

Keywords: *active packaging, intelligent packaging, household food waste, consumer's willingness to purchase*

WHY DO PEOPLE COMPLAIN ABOUT PACKAGING? – A NETNOGRAPHIC CASE STUDY OF CONSUMER COMPLAINTS DERIVING NEEDS FOR PACKAGING REDESIGN

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Packaging heats tempers so that stakeholders along the value-chain ask for optimization. Current patterns of resource use, mostly addressing end-of-life-scenarios, led to politics putting this issue on its agenda (e.g., A European Strategy for Plastics in a Circular Economy). Packaging producers and science work on design for and from recycling, brand owners and retail try to reduce plastic amounts and waste management focuses collection, sorting and recycling improvements (e.g., Design Guidelines, The Global Commitment). While a lot of movement is going on and people dedicate work to improve packaging solutions, consumers still feel unheard and seem to perceive packaging as being e.g., unsustainable, unnecessary or misleading. This dissatisfaction has a certain power to support or undermine actions improving packaging sustainability and induces necessary discussions reflecting the stage of consumption.

Overall, dissatisfaction might lead to hardly visible exit scenarios (i.e., don't buy product again), but it also results in publicly available discussions online, that consumers use to make their voices heard. People share pictures, thoughts, and feelings. The uploaded content is available for a long time, sometimes for years and continues to promote the bad reputation of products, producers or packaging.

Taking a closer look at this user generated content via netnography as research method and understand what exactly bothers people, is a chance to optimize packaging beyond conventional perspectives. It is, for example, a starting point

to introduce consumers needs more into redesign, if necessary, through legislative changes that protect better from misleading packaging. This could improve how people perceive the packaging's value, how they handle it and engage in the needed steps to improve the overall sustainability of products (e.g., recycling behavior).

To understand dissatisfaction with packaging at consumption, over 200 virtual cases of complaints shared online by consumers were collected. During an analytical phase, the cases were coded by a group of researchers to define complaint contents, as well as categorized and integrated into a framework, based on the stimulus-organism-response model (packaging specifics, consumer motives, complaint outcomes). The qualitative analysis to source reasons of dissatisfaction, as well as the question on how to prevent such outcomes, were the focus areas of the study.

The findings indicate that the basic packaging function of communication is in most cases the origin of dissatisfaction, weather if it stems from implicit design like sizes or explicit elements like text-based information. Multiple complaints are about showing or hiding specific product parts. The concern of packaging being unsustainable is also present in the sample, e.g., reflecting unpacking and repacking of products with natural protective peels or shells. In the current data, some product groups lead the looked-up discussions more than others do (e.g., confectionery, fruits & vegetables).

Summing up first results, a need to improve implicit and explicit communication is visible and packaging redesign could make a change. If the communication function of packaging is not met, consumers can´t be part of an economy, where their perceptions and interactions also determine sustainability – they will continue to ask for skipping packaging and science will ask why, as it is thought to be already optimized to its best.

Keywords: *netnography, packaging redesign, complaints, consumer, communication*

INTELLIGENT PACKAGING FOR REDUCING FOOD WASTE – A CONSUMER PERSPECTIVE

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Food waste is a major contributor to global environmental problems. Extending the shelf life of perishable food products can reduce food waste. The printed shelf life on products has to include a safety margin based on non-optimal temperatures that may occur in the supply chain. This implies that the actual shelf life will be longer if the temperature is well controlled. An intelligent packaging can be used to determine a dynamic shelf life based on the actual conditions in the supply chain. By using a data base of a large number of time-temperature combination of the different steps in the supply chain a simulation of the actual shelf life was performed. Food waste of salads at retail was found to be reduced from 12.5% to 2% by implementing a dynamic shelf life.

After sale of products also quality changes at household level have to be considered. Temperature measurements in 70 consumer fridges at different locations have been done. Results show a broad range of temperatures of which a large proportion is above the recommended temperature. This will result in shorter shelf lives and more food waste. Intelligent packaging may affect consumer behaviour with respect to food buying and storage.

Before implementation, consumers have to accept and trust intelligent packages. A consumer survey was done to study the effect of the type of indicator on the acceptance and trust of the packaging. It turned out that a simple colour indicator was best accepted, but was preferred to be in combination with the printed shelf life.

Keywords: *food waste, consumer, acceptability, dynamic shelf life, refridgerator temperature*

CONSUMER DRIVERS FOR MUSHROOM PACKAGING – MORE SUSTAINABILITY AND LESS FOOD WASTE

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Understanding consumer attitudes towards innovative food packaging, such as biobased active packaging, is essential for developing a packaging technology with desired features and functions. Further, consumer preferences for sustainable packaging features/functions also depend on the specific food product being considered. With the aim to assess consumer knowledge, interest, and willingness to pay towards sustainable packaging (including biobased active packaging) for mushroom, a survey questionnaire (24 questions) was distributed online among target participants (age 18 years and above, mushroom buyers, and residents of Ireland) through various social media platforms. Complete response data from 318 participants (representative of the national population in terms of provincial distribution, urban/rural distribution, education and household income levels, as per Census 2016) were statistically analysed using IBM SPSS Statistics (version 28).

Participants showed a general lack of knowledge of active packaging (77.7% not having heard the term), however they were more aware of biobased packaging (56.9% having heard the term). While there were no significant differences in participants of different age groups, urban/rural distribution, and household income levels; knowledge of active packaging and biobased packaging was positively correlated with higher level of education. Participants were most interested (56.9%) in a new packaging that can improve the shelf-life of mushrooms, with no statistical differences observed based on their demographic characteristics, knowledge of mushroom packaging, mushroom storage habit, and frequency of discarding mushrooms after purchase. Overall, participants preferred compostable non-plastic (84.0%) over recyclable plastic (11.0%) for their choice of sustainable packaging material. With regards to biobased active packaging for mushroom, upon becoming aware of its

attributes, most participants (88.4%) were willing to pay ten percent extra for mushroom in biobased active packaging.

Our novel study highlights that mushroom buyers in Ireland acknowledge their part in the generation of food waste; and that they are willing to pay a little extra for sustainable packaging alternatives that increase shelf-life, thereby reducing food waste. Given sufficient information, they are also willing to adopt packaging innovations, such as biobased active packaging. Consumer adoption of such packaging innovations could contribute towards one of the United Nations Sustainable Development Goals which targets to halve per capita global food waste at retail and consumer level and implies to substantially promote the use of sustainable materials by 2030.

Keywords: *consumer, sustainable packaging, biobased active packaging, mushroom, food waste*

SUSTAINABLE PACKAGING FOR FISH AND MEAT: INDUSTRY INSIGHTS

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Food packaging is an important service of food marketing as it is crucial to not only provide information but also preserve the nutrients, quality and safety of the product. It is essential to improve food packaging sustainability and to assure its circularity, that is that the packaging is designed to be safely reused, recycled or composted, ensuring that the material produced stays in the economy and does not become waste.

The purpose of WG2: Meat and Fish of the CIRCUL-A-BILITY Cost Action is to define the best sustainable, circular meat and fish packaging solutions while ensuring optimal food quality, preventing food waste, and improving consumer experience. In order to identify the technical limitations and opportunities to develop sustainable packaging systems WG2, has focused in gathering information about the state of the art on fish and meat packaging. With this purpose, an online survey on sustainable packaging for fish and meat addressed to the meat, fish and packaging industry was carried out.

57 companies from 13 countries participated in the survey, with 96% of the companies based in Europe. 60 % of the respondents working in large companies with more than 250 employees, and a turnover higher than €50 million. 83,5 % of the respondents declared that packaging circulability was

important for their company. When asked about the most challenging products to make packaging circular, respondents from the fish and meat sector pointed out fresh fish and meat as well as ready meals the most challenging products. On the other hand, respondents from packaging companies found that the most challenging products were fresh fish and meat as well as ready meals. It can be seen that respondents of the three sectors found the same products challenging in order to make packaging circular.

Material reduction, and the use of recyclable and recycled material are the strategies in which companies invest more to improve the circularity of their packaging, while reuse and the use of biodegradable materials would be the ones with least investment. Actually, only 30,6 % of the companies used biodegradable materials to pack their products. Paper and cardboard and other fiber based materials (52.2%), PLA (15.2%), cellophane (10.9%) and PVOH (10.9 %)are the most used materials.

In terms of communication, 64.3% of the companies that particpated in the survey communicated sustainability information on their packages. The information provided was mainly related to the end of life of the material (82%), material's origin (53%), and recycling information (53%). It should be highlighted that only 18% of the companies gave information on the environemental impact of their packaging choices.

Finally, the participants noted the focus of the future research to make fish and meat packaging more circular. For the respondents, next research agendas should shed light on the material attributes such as availabitliy, recyclability, mechanical and barrier properties, and on food protection. Apart from this brief outcome shared here, statistical analysis methods such as descriptive statistics and t-test were applied to gain deeper insights. The results are interesting to different stakeholders such as other researcher, the food and packaging industries as well as policy makers.

Keywords: *food packaging, sustainability, food marketing*

PLASTICS, FIBER OR NO PACKAGING FOR FRUITS AND VEGETABLES; DEVELOPMENT OF A TEST PROTOCOL FOR DECISION MAKING

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Increased awareness of the climate crisis and plastic pollution of the seas has led to increased pressure from consumers to reduce the use of plastic packaging, especially this applies to fruits and vegetables (F&V). Most consumers lack the knowledge that plastics and packaging in general also preserve food quality. Documentation showing that packaging is necessary and contributes to longer shelf life and less food waste is requested. Previous scientific studies, both nationally and internationally, have to a small extent compared quality of products with and without plastic packaging. Hence, few scientific data on the effect of plastic removal is available, and the few accessible international studies are not relevant for Norwegian distribution conditions.

The focus on reducing plastic consumption has led to the offering of a range of renewable, fiber-based packaging solutions, with and without different coatings. Generally, plastic has a better ability to preserve product moisture than fiber, and fiber cannot be used for all types of F&V. To our knowledge, there are no easy access to information on which products that can be packaged in fiber materials without compromising on packaging stability and product shelf life through the distribution chain and at the consumers. The aim of the work was thus to develop a knowledge-based, rapid, industry adapted, and robust test protocol for choosing the correct packaging for F&V stored under different temperature scenarios. Furthermore, the test protocol was used to evaluate shelf lives of selected case products.

Initially, an overview covering different F&V with common cultivars, country of production, growth season, type of packaging available, and typical shelf life and storage temperatures through the distribution chain, was set up. From this

overview, products were selected for further study, evaluating both single packaged produce, such as cucumbers, and multiple items in trays and clamshells, such as tomatoes. Products and test conditions were chosen in close collaboration between industry and researchers. The selected products were stored in plastics, fiber and in no packaging under optimal and realistic temperature scenarios. Weight loss (dehydration) of the products were registered during storage, as well as quality changes evaluated by simple sensory assessments. The sensory properties to be analysed were adapted to each product and were in line with quality requirements and tolerances given by the industry.

This work describes a) the layout and main elements of the test protocol including information about product, packaging, storage scenarios, methods for quality evaluation and a template for presentation of results and b) main conclusions with selected products shelf-lives under different temperature scenarios. The developed test protocol is designed to be flexible and will continuously be improved and adapted to be used for different F&V making it possible to streamline testing of future packaging solutions. The information gained from the shelf life studies will further be communicated to the consumers to promote awareness of the importance of packaging to preserve food quality.

Keywords: *optimal packaging, temperature scenarios, sensory assessment, quality evaluation, weight loss*

INNOVATIVE FOOD PACKAGING NANOMATERIALS IN POSTHARVEST PRESERVATION OF FRUITS AND VEGETABLES

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Fruits and vegetables are perishable products and differ in the natural and biochemical characteristics of other foods of plant origin (cereals, legumes, nuts). The main problem in the post-harvest management of these foods is that due to their high moisture content, high respiration activity, and microbial infections lead to rapid deterioration with undesirable appearance during storage and transportation. Preventing the ingress of gasses, water, and vapor and maintaining a modified environment to diminish respiration, extend shelf life, and prevent loss/change of flavor and color during storage, are common postharvest practices which can be achieved with packaging.

In recent years, nanomaterials have found a wide range of applications in food science and packaging due to their promising properties. Nanomaterial is defined as material having one or more dimensions in the range of 1–100 nm. Due to their very small size nanomaterials' chemical, biological, electrical, thermal, mechanical, optical, and magnetic properties are different from those of the bulk materials, although these materials have the same chemical composition as conventional ones.

Innovative nanomaterials or nanostructures have been synthesized, and their properties have been investigated for active and intelligent food packaging applications. In the postharvest management of fresh fruits and vegetables, nanomaterials contribute to their better preservation by antifungal-containing food packaging materials that are capable of inhibiting the development of postharvest diseases and ethylene production as well as by monitoring quality parameters with nanosensors. Additionally innovative food packaging films can be used to prevent the effects of gases and dangerous rays.

Edible coatings and films are also used in the postharvest management of fruits and vegetables as an emerging technology that significantly contributes to extend the preservation time. Especially in the postharvest storage of fresh-cut fruits, prolonging shelf life through edible coatings is achieved by decreasing moisture, respiration, and gas exchange as well as with the reduction or even suppression of physiological disorders. Moreover, a wide range of capable nanosystems have been developed as important tools and efficient options for the control, limit, and improvement of safety and qualitative parameters of fruits and vegetables.

Keywords: *food packaging nanomaterials, fruits and vegetables, postharvest management, quality and safety, storage*

FOOD CONTACT MATERIALS AND THE ISSUE OF CHEMICAL MIGRATION

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The food packaging itself has been found to represent a significant source of contamination through the migration of substances from the food contact material (FCM) into the food. Even though FCM manufacturers are required to evaluate their products with respect to intentionally and non-intentionally added substances (IAS & NIAS), no guidelines for carrying out such a risk assessment are provided by the responsible authorities.

The difficulties in the analysis of food packaging migrants are resulting from the many existing chemical classes of IAS and NIAS, the lack of analytical standards for many of them and the fact that several of these substances are not yet included in chemical or spectral databases. Considering that the safety assessment of commonly used plastic materials is still a work under progress, the evaluation of new materials and materials of a more complex nature opposes a greater challenge to the scientific community.

To facilitate the comprehensive IAS & NIAS screening, we employed different sample preparation protocols, accompanied by a wide range of hyphenated analytical techniques. In particular, we developed GC-EI-MS/MS, GC-CI-MS/MS and GC-APCI-QTOFMS methods for the target screening of volatile IAS & NIAS, as well as LC-MS/MS and LC-ESI-QTOFMS methods for corresponding migrants of low volatility, thermal instability and higher polarity. Characteristic applications of the developed workflows in the analysis of original and recycled FCMs will be presented, utilizing the entire spectrum of liquid food simulants, while evaluating different migration and sample preparation protocols.

Screening of migrating chemical contaminants is of paramount importance for the production of safe next generation FCMs. The need for sustainability promotes the development of FCMs that are safe for the consumers and environmentally friendly. Thus, target of our research work is to assess corresponding public health risks, meeting the challenges of the present and the future.

Keywords: *IAS, NIAS, FCM, migration*

PACKAGING SUSTAINABILITY COMMUNICATION IN THE FOOD INDUSTRY: AN APPLICATION TO WET SOUPS

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The way we package our food needs to be more sustainable in the future. Only recently research has focused on how consumers react to environmentally friendly packaging. Findings have shown that while consumers give less importance to environmentally friendly packaging, compared to other product attributes (Martinho et al., 2015), they are more willing to buy products with a packaging less harmful to the environment (Magnier and Schormans, 2015).

Keywords: *sustainability communication, environmental labeling, environmental product declaration, packaged soup*

RECYCLABLE MATERIALS IN PACKAGING ATLANTIC SALMON PORTIONS ORIGINATING FROM REFRIGERATED SEAWATER AND SUBCHILLED STORAGE

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Food packaging plays multiple important functions, including ensuring the quality and safety of food products. Nevertheless, using complex laminated structural materials for food packaging reduces recyclability as such materials can be difficult to recycle. The use of mono-materials for food packaging enhances recyclability and contributes to a more circular economy. In the fish industry, subchilling whole gutted fish in refrigerated seawater (RSW) below 0°C is practised, slaughtering fish directly by the sea cages instead of land-based slaughter and traditional ice storage. This study evaluates the effect of subchilled RSW storage on Atlantic salmon through the whole value chain, to filleting, portioning, modified atmospheric packaging (MAP, 60%CO2:40%N2) and subchilled storage at -1°C. The control group were ice-chilled whole fish stored at 0°C, then at 4°C after packaging. Two types of mono-material packaging materials in trays were examined in both storage methods after portioning, a crystallized polyethylene terephthalate (CPET) tray versus a high-density polyethylene (HDPE) tray. Suitable top web materials were applied. The RSW and ice-stored fish were monitored for a total of 56 and 21 days, respectively. Quality and shelf-life parameters were periodically analyzed, including gas composition, drip loss (DL), water holding capacity (WHC), texture, and microbiology.

The temperature of the RSW fish was maintained at -1°C for 7 days, where the fish was immersed in RSW for 4 days, then stored on boxes without ice for 3 days before further processing. Fish immersed in RSW resulted in an overall weight gain of 0.4±0.3% and a better WHC on day 7. CPET trays had lower

*oxygen transmission rates, measured as ml/(package*day), at both subchilled and chilled conditions than HDPE. Portions packaged in CPET trays had a lower O2 concentration than when stored in HDPE, regardless of the whole fish storage method. As expected, the CO2 decreased within the packages for all groups through storage time. In addition, fish originating from RSW storage had a lower CO2 and higher O2 concentration within the packages than the iced fish. The RSW fish packaged in CPET trays gave the highest drip loss. Textural parameters indicated a decrease in breaking force and firmness for all groups. The microbiological shelf life of ice stored fish ended on day 14 post mortem. In contrast, the RSW fish had around 3 times longer shelf life. This study presents the possibility of storing salmon in monolayer recyclable trays while extending the quality and shelf life at subchilled storage conditions through the whole value chain.*

Keywords: *monomaterial, subchilling, quality, shelf life, Atlantic salmon*

MULTIPLE MECHANICAL RECYCLING OF PET MODIFIES ITS PHYSICAL AND CHEMICAL PROPERTIES. IMPLICATIONS FOR ITS APPLICATION IN FOOD CONTACT MATERIALS

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It is necessary to increase our ability to reuse and recycle food contact materials (FCM) to improve the circularity of our food system. Currently, only 10% plastic is recycled, but the new EU plastic waste strategy requires by 2030 to include at least 30% of recycled material in packaging. Although many studies have been carried out on recycled plastics, very few of them have focused on multiple recycling steps and their effect on the material properties. Polyethylene terephthalate (PET) is currently the only polymer that can be used in its recycled form for food packaging in Europe. Therefore, in this study, PET was chosen as a model system and exposed to four consecutive extrusion cycles to simulate mechanical recycling. For that purpose, a laboratory-scale twin screw extruder was used, adopting the following temperature profile (from feeder zone to die zone): 230 °C, 240 °C, 250 °C, 260 °C, 260 °C, 270 °C, 270 °C, 250 °C and a screw speed of 100 rpm. Samples were then characterized by differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) to investigate physical and thermal properties. The potential changes in the polymer's chemical composition and presence of byproducts of recycling were instead tested using matrix assisted laser desorption ionization-mass spectrometry (MALDI-MS). From DSC we can see that in the reprocessed materials, during the cooling phase, crystallization occurs earlier for samples subjected to increased number of extrusion cycles. Moreover, the Tg of reprocessed samples shows a decrease compared to the vPET. TGA did not indicate any significant changes in the decomposition temperature of rPET pellets compared to vPET. The MALDI with negative ionization run on the recycled pellets revealed the presence of certain

target cyclic and linear PET oligomers. It was concluded that, under the selected experimental conditions, the recyclability of PET was limited to a few cycles. At the 4th cycle there was an obvious change in thermal profile as well as a decrease in the molecular weight of the polymer. In addition, the MALDI-MS data indicated that it may be possible to follow the history of the FCM, and particularly of PET, over its end of life. This work demonstrates the importance of understanding the history of rPET and its potential interaction with the food product, to ensure the appropriate protection and safety of the food that it contains.

Keywords: *food contact materials, polyethylene terephthalate (PET), recycling, thermal properties*

DIGESTION OF POLYSTYRENE NANOPARTICLES IN A WHEY PROTEIN DRINK. A SIMULATED IN VITRO GASTROINTESTINAL DIGESTION USING A BATCH INFOGEST MODEL COMBINED WITH CELL ABSORPTION EXPERIMENTS

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The small fragments of plastic material are becoming of great concern, as they can find their way into the environment and in the food we consume. The objective of this project was to evaluate the fate of nano and microplastic particles of well known size, during gastrointestinal transfer, after mixing them with a whey protein suspension. The cytotoxicity of polystyrene latex particles (60 nm and 1 µm, monodisperse) and exposure experiments were performed using confluent Caco-2 cells with undigested samples. The cytotoxicity was determined by MTT assay with concentrations that ranged from 25 to 500 µg/mL after 24 h, with no statistical differences observed in cell viability. The polystyrene latex exposure effect was assessed for 24, 48 and 72 h at a concentration of 500 µg/mL, and media and cells were collected for further analysis. Moreover, polystyrene latex particles at a concentration of 68 mg/mL were mixed with 5% (w/v) whey protein solution and subjected to the INFOGEST digestion protocol. Oral, gastric (2 h) and duodenal (2 h) phases of digestion were performed at 37 °C. Microstructure analysis and particle size measurements of resulted digested samples were performed by confocal microscopy and laser light scattering, respectively. Digested samples were then diluted 1:16 to test their cytotoxicity for 4 h in confluent Caco-2 cells and results

showed no cytotoxic effect. Intestinal permeability experiments were performed in 21 days differentiated co-cultures of Caco-2/HT29-MTX. Differentiated co-cultures were exposed to digested polystyrene latex particles for 4 hours, and samples of cells, apical and basolateral contents were collected for further analysis. Samples from the exposure, digestion and permeability experiments were analysed using mass spectrometry (MALDI, GCMS). This work for the first time shows the digestion of polystyrene latex particles (60 nm and 1 µm) and their permeability in models of the intestinal barrier.

Keywords: *polystyrene nanoparticles, whey protein, digestion, cell absorption*

COMPOSTABLE IS BETTER? THE CASE OF COFFEE CAPSULES STORED UNDER DIFFERENT HUMIDITY AND TEMPERATURE

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The impact of single-use plastic products (SUPs), i.e. used once or for a short period of time before being thrown away, on the environment and on our health is global and dramatic. To tackle plastic pollution, the EU issued the Directive (EU) 2019/904 that pushes the Member States to adopt national legislation ensuring the replacement of certain SUPs with more sustainable alternatives. As an answer, food business operators urge to identify alternative solutions to conventional plastic-based materials, which can be regarded as SUPs. Following this trend, several compostable packaging materials have recently appeared on the market. However, the impact of SUPs replacement with these novel materials on food quality over storage, and thus shelf life, is still largely unknown.

One of the major issues regarding compostable packaging materials is their susceptibility to moisture uptake, which is considerably higher compared to that of conventional packaging. Moisture absorption is expected to be particularly challenging in the case of shelf-stable dry products, due to its direct (e.g., softening of crunchy products) and indirect (e.g., triggering of alterative reaction) drawbacks during prolonged storage. Nevertheless, to the best of our knowledge, no evidence exists on the rate and extent of moisture uptake by shelf-stable food packed in compostable material.

In the present research, coffee was selected as a study case of shelf-stable dry foods to understand how the replacement of conventional packaging with

compostable materials could affect its quality. For this purpose, ground coffee packaged in capsules made of conventional (control) or PBS industrial compostable material was stored under different environmental relative humidity, ERH (23, 54, 65 e 75%), and temperature, T (4, 20, 30 e 45 °C) for up to 1 year. Coffee moisture (M) uptake and water activity (aw) were selected as quality indicators being typically associated with quality decay. While no significant M and aw changes were detected during the storage of control coffee capsules, these parameters progressively increased, equilibrating with ERH, when coffee was stored in compostable capsules. Under the most extreme conditions (i.e., 45 °C and 75% ERH), equilibrium was reached within just 3 months, which often corresponds to the time span necessary for the product to barely reach the supermarket shelves. It is noteworthy that these environmental conditions could represent a realistic worst-case scenario, especially for shelf-stable dry food that undergoes long shipment or warehousing in the absence of T and ERH control.

Acquired results strongly indicate that replacing conventional packaging with compostable materials requires a deep understanding of their effects on food quality evolution, jointly with the awareness of the boundaries beyond which the product is no more acceptable to the consumers. This knowledge is essential to avoid that replacing SUPs with more sustainable materials would imply an increase in the risk of food wasting, which might be even more impacting than SUPs themselves.

Keywords: *coffee, dry food, shelf-life, temperature, humidity*

BIOACTIVE PACKAGING: WHAT IS NEW?

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Recently, interest is rising in the use of bio-based materials in the packaging industry. In this context, the use of agricultural and industrial by-products and waste streams constituted a boom and revolution in the field of extracting bio-based substances on the one hand, and on the other hand, an optimal and safe solution (eco-friendly) for the disposal of these wastes. For example, agricultural by-products are major sources of polysaccharides (e.g., agar, chitosan, cellulose, and starch) that are recently used in the food packaging industry as sustainable biodegradable alternatives to replace plastics that are a significant environmental burden. However, at a European Union (EU) level there is no clear regulatory framework for these materials, something that consequently affects their risk assessment, which at the moment is very limited. The use of bioactive packaging is not only positive for the environment but also plays an effective role in promoting consumer health through eating healthy packaged foods, which can be considered an innovative strategy for the production of functional foods. Among the recent applications of biologically active packaging that highlight its importance is the recent study conducted by a group of researchers in Canada in the Quebec region on strawberries. The purpose of the study was to maintain the freshness of the strawberry using an innovative bio-package consisting of chitosan (a natural substance extracted from oyster shells), essential oils, and nanoparticles, all of which are characterized by their antimicrobial properties. This was confirmed and proven by this study, which showed that this innovative bioactive coating was able to keep strawberries fresh for up to 12 days. Despite the increasing pace of efforts to develop such types of packages based on sustainable biomaterials, their use on a broader commercial level is limited by many hurdles that need to be more work to overcome, including, for example, their mechanical, thermal, and physical properties, which are still not satisfying. Therefore, it is necessary to

give more attention and highlight the active packaging technology as a promising technology in the world of food packaging.

Keywords: *bioactive packaging, agricultural by-products, food*

A STUDY ON STORAGE OF APPLE (MALUS DOMESTICA) WITH ZEOLITE-FILLED PAPERS

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The continuation of respiration of apple fruits in the post-harvest period, the release of high amounts of ethylene gas and carbon dioxide increase their respiration during storage, transportation and shelf life, thus accelerating the fruit's ripening and softening. In this study, the storage conditions of climacteric apple species (Malus domestica) with 180 grammages (g/m2) paper with 15% zeolite in rooms (20-23 °C and 45-55% relative humidity) and cold (1-5 °C and 90 -95% relative humidity) storages. The storage process was carried out under the mentioned room and cold conditions by preparing a box covered with filler-free and zeolite-filled papers, placing five weighed apples in the boxes and wrapping them with cling film. The effects of zeolite-filled papers on ethylene, carbon dioxide, oxygen gases and quality characteristics of apples were investigated for 4 weeks.

Keywords: *apple, Malus domestica, paper, zeolite, storage*

BIO-BASED FOOD PACKAGING MATERIAL FOR INTELLIGENT FOOD PACKAGING APPLICATIONS FOR CHICKEN FILLETS

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Bionanocomposite packaging is made up of bio- based materials that have high performance activity and are ecologically sustainable alternatives to packaging made of synthetic polymers. Intelligent packaging retains track of the state of the food and the environment in which it is stored, and communicates relevant changes to the consumer through visualization or other methods. The aim of this study was to develop a bionanocomposite intelligent packaging material by utilising sodium alginate, gelatin, nanoclay and curcumin. Sodium alginate, gelatin film incorporated with Curcumin (Cur), and Nanoclay (NC) in various concentrations (0% W/V, 0.5% W/V, 1% W/V and 1. 5% W/V) were prepared using the solvent casting method. The influences of nanoclay and curcumin on the optical, mechanical, physical, chemical, thermal, antibacterial and pH indicating properties were studied using a variety of techniques. All sample films were of high coloration and low transparency with a ΔE> 4. The thickness of all the film were around 0.08 mm and SA_Gel_Cur_1. 5%NC had the most effective UV barrier properties. The transparency of the films decreased and the UV barrier properties increased with the increasing NC concentrations. FTIR spectra of all samples were very similar, with no alterations to the control's functional groups. SA_Gel_Cur_1.5%NC had the most favourable combined mechanical properties with the highest tensile strength (4.15 ± 0.22MPa), and elongation at break of (6.14 ± 0.39%). All the films are hydrophilic in nature with < 90 contact angle. No films exhibited antibacterial properties against E. coli and S. aureus. Curcumin present at 0.3 W/V% was an effective pH changing indicator which changes from orange to red in alkaline conditions. When tested on chicken breast fillet the developed intelligent packaging film changed to red*

with the increasing storage time up to 15 days. The developed films had an effective UV barrier capability and pH indicating properties and therefore can be used as smart food packaging to improve the quality of and increase the shelf life of foods. Further, recommendations suggest introducing essential oils or other antimicrobial agents to the bionanocomposite to improve the antibacterial efficacy.

Keywords: *intelligent packaging, nanoclay, sodium alginate, gelatin, curcumin*

LAVENDER EXTRACT SURFACE TREATMENT OF PACKAGING PAPER FOR ANTIMICROBIAL ACTIVITY

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Nowadays for the food industry, quality maintenance, food preservation and safety are major growing concerns. It is evident that over the time consumers' demand for natural and safe food products with stringent regulations to prevent food-borne infectious diseases has been growing. Antimicrobial packaging is defined as a packaging material with biological properties that allows its interaction with the product or the headspace inside to reduce, inhibit, or retard the growth of spoilage or pathogenic microorganisms on food surfaces. Static extraction with 70% ethanol was performed at a raw material solvent ratio of 1:10, temperature 60 °C and duration 5 hours. Different cellulose packaging papers have been one side surface treated with the lavender extract (with relative density - d 20/20 = 0,8927 ± 0,005; refractive index – n=1,3723 ± 0,002 and dry matter content 2,10 ± 0,05, %). Results indicate the inhibition activity of the obtained coated paper samples on the growth of Gram-positive Bacteria Staphylococcus aureus ATCC 6538 in the range of 1.5-5.3%; at Gram-negative bacteria Escherichia coli ATCC 8739 in the range of 7.2-9.3 %; at yeast Candida albicans ATCC 10231the decrease in the number of viable cells is in the range of 3.1-9.4% and at fungi Aspergillus brasiliensis ATCC 16404 in the range of 1.6-6.1%, depending on the type paper used. The results show that the treatment of the investigated cellulose papers has an effect on the growth of the test microorganisms used and the papers treated with lavender extract poses antibacterial activity.

Keywords: *antimicrobial activity, packaging, paper, lavender extract*

IMMOBILIZATION OF ESSENTIAL OILS AND THEIR COMPONENTS IN STARCH SODIUM OCTENYL SUCCINATE FOR ACTIVE PACKAGING APPLICATIONS

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In the present study the emulsions of clove essential oil, eugenol or cinnamon aldehyde and starch sodium octenyl succinate were formulated and their application in active food packaging was investigated. The aqueous emulsions containing 2.5, 5 and 10 percent (w/w) of active components were prepared and assessed. The emulsions droplet size depended on active components used and their concentration in the formulation. The smallest droplets were characteristic of cinnamon aldehyde containing emulsions (286-308 nm), the larger ones were determined in the emulsions with clove essential oil (296-491 nm) and the largest droplets were measured in the case of eugenol emulsions (228-650 nm). The stability of emulsions was assessed by following the changes in size of the droplets and their sedimentation. It was found that the most unstable were the emulsions containing cinnamon aldehyde and eugenol due to significant increase in droplet size during storage i.e. the stability of all emulsions decreased by 4-5% when stored at 4 ºC for 16 days.

The active coatings were obtained by casting emulsions on paper. The antioxidant properties studies of coated paper revealed that high antioxidant activity was characteristic of clove essential oil emulsions coatings (76-92 %) and eugenol emulsions coatings (87-91 %), meanwhile, coatings containing cinnamon aldehyde showed quite low antioxidant activity (4-9 %). After 27 days the antioxidant activity of the coatings deteriorated, however, the trend remained.

The antifungal activity of coated paper samples was evaluated by applying them in packaging of white bread slices. After 27 days of storage at 22 ± 2°C mold was visible on the control samples. However, mold was also observed on some samples packaged by using coated paper. The best results were obtained

using paper samples coated with emulsions containing 2.5, 5 and 10 % cinnamon aldehyde, when all bread samples were protected from mold formation. Consequently, the results of this research allowed to envisage the possible application of antifungal packaging with cinnamon aldehyde as a promising technology for increasing the shelf life of bakery products.

Keywords: *clove oil, eugenol, cinnamon aldehyde, starch sodium octenyl succinate, active coatings*

ANTIMICROBIAL ACTIVITY OF DIFFERENT NANOCELLULOSE FILMS EMBEDDED WITH THYME, CINNAMON AND OREGANO ESSENTIAL OILS FOR ACTIVE PACKAGING APPLICATION ON RASPBERRIES

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In this study we analyzed the antimicrobial activity of nanocellulose films with a different carboxymethylation degree activated with thyme, cinnamon and oregano essential oils for active packaging application. The tests have been performed both in vitro with the most common pathogen bacteria, and in vivo on clamshell type packed raspberries, in order to have a better understanding of the system and observe the quality parameters of the fruit.

The in vitro tests were based on the use of microbiological agar plates and showed that the dimensions of the nanocellulose films and the quantity of essential oil have a strong influence on the antimicrobial effect. In particular, the thyme essential oil is the one having 100% of antimicrobial effect with a quantity of 0.41 µl/mg of matrix (NFC). While oregano reaches the same antimicrobial activity with 0.65 µl/mg. For all the oils, the major effect was demonstrated against the only Gram-positive bacterium tested, i.e., a Staphylococcus aureus strain.

The minimum inhibitory concentration (MIC) of the essential oils was evaluated for the in vivo test. It was observed that thyme and oregano essential oils were effective in maintaining firmness and less weight loss than cinnamon essential oil or controls, through 12 days storage at 1 ºC. There was no significant effect of the essential oils on the other quality parameters measured. Also, they were effective in reducing microbial growth during storage. From the results of this experiment, we can conclude that active packaging including the thyme and oregano essential oils is a promising technology to improve shelf-life of raspberries.

Keywords: *antimicrobial activity, active packaging, essential oil, nanocellulose*

INFLUENCE OF KERATIN ON PHYSICOCHEMICAL PROPERTIES OF NANOCELLULOSE-BASED FILMS.

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Confronted with the deterioration of the environment, due in part to the manufacture and use of plastics, the packaging industry has needed to reinvent itself and find more environmentally friendly alternatives to synthetic plastics. For decades, the majority of packaging has been made of synthetic petroleum-based plastics. It is a proven fact that this type of plastics causes major environmental problems due to their synthesis and their management at their end of life. For this reason, France has implemented restrictions on the use of synthetic plastics and is encouraging manufacturers to adopt more bio sourced methods and processes that are less costly for the environment. This research does not only apply to environmental criteria but also to performance criteria. As a result, research is turning to new materials that are more environmentally friendly and that have the expected performance. One of the solutions consists on the bio sourced and/or natural polymers, renewable and low-polluting. Cellulose is one of them, is a naturally abundant material. Indeed, cellulose packaging, in the shape of films for example, has been developed but nevertheless there are several disadvantages that limit its use in packaging. In particular, its hygroscopicity prevents a good resistance to water, an essential property for the food industry. This work presents a solution to the lack of water resistance of cellulose films. Various formulations of cellulose films have been made with the addition of keratin extracted from duck feathers. These feathers are recovered to reuse them and to create an added value while limiting the agri-food waste. Keratin is known to be an insoluble cysteine-rich protein with natural hydrophobicity properties. The keratin additions are 5, 10, 15 and 20 %. A comparison of the physico-chemical characteristics of these films was carried out. Mechanical properties such as tensile stress and elongation at break were

studied using a universal testing machine. The degradation temperature of the films was analyzed by Thermogravimetric Analysis (TGA). Hydrophobicity of films with keratin additions was measured using contact angle. The films morphology was followed by microscopic analysis using a Scanning Electron Microscope (SEM). The extracted keratin added to the films has a color so the influence of the keratin on the films color was followed with a colorimeter. Finally, their opacity was measured with a UV spectrophotometer. After comparison of the films without addition and with different additions of keratin the results show motivating perspectives for the elaboration of composite films based on cellulose and keratin with complementary properties brought by each compound.

Keywords: *nano-keratin, cellulose, films, bioplastic, duck feathers*

VALORIZATION OF GARLIC PEEL AS AN ADDITIVE FOR THE DEVELOPMENT OF BIODEGRADABLE PAPER COATINGS

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During garlic processing, garlic peels (GP) are retrieved as byproduct both in a domestic and industrial context. Current GP valorisation is centred in the study of its antioxidants and flavonoids for antimicrobial and anticancer applications [1,2]. However, other GP molecules, including carbohydrates, proteins, and lipids, are still discarded. On the other hand, targeting to minimize the ecological footprint of paper-based packaging sector, biobased coatings are required as alternative to the often-used non-biodegradable petroleum-based plastics. In this work, the feasibility of using crude GP as an additive to make a commercially available biobased plastic (Biopar®) compatible with the surface of paper-based materials was studied.

Grinded GP was successfully melt-mixed with Biopar® in different concentrations (5%-20%), conferring a brownish coloration to the bioplastic material, whose intensity was directly dependent on the GP dosage used. GP decreased the Biopar® melt flow rate (MFR) from 18.4 g/10 min to 2 g/10 min, thus decreasing the Biopar® melt tenacity. Biopar®/GP-based formulations were successfully attached onto the paper surface for all the GP concentrations studied, allowing to increase the papers water contact angle (WCA) from 94.8° to 105.3° and its tensile strength from 34.4 MPa to 99.5 MPa. Therefore, GP revealed to be a promising additive to enhance the Biopar® affinity with the paper surface while conferring water tolerance and tensile resistance to the coated material, opening an opportunity to valorise GP while offering a disruptive eco-friendly approach for paper coating.

Keywords: *starch, garlic peel, biodegradability, paper*

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THE COMPOSITION INFLUENCE ON PHYSICO-MECHANICAL PROPERTIES OF BIOPOLYMER FILMS BASED ON EDIBLE OIL CAKES

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The problem of packaging waste relies on the massive application of polymer materials, obtained from non-renewable sources, which, as disposed packaging, present great threat to the environment. On the other hand, a large quantity of biomass/agoindustrial products/food represents serious waste worldwide, which is also an unfavorable situation.

Even though a certain percentage of agroindustrial waste is classified as a by-product, it is currently underutilized. Agroindustrial by-products could be considered as a valuable source for biopolymer film processing. Following the extraction of edible oil from oilseeds, a valuable by-product known as cake or meal remains. These materials present a suitable substrate for eco-friendly biopolymer packaging materials due to their composition (high protein and carbohydrate content).

Previous investigations have shown that it is possible to produce biopolymer materials based on different edible oil cakes; that these materials can be used to form packaging units that can withstand the conditions of the modified atmosphere; that they can be used for food packaging, etc.

In this paper we chose 3 various oil cakes: sunflower, pumpkin and flaxseed. Four cake mixtures (50% sunflower + 50% pumpkin, 50% sunflower + 50% flaxseed, 50% pumpkin + 50% flaxseed and mix of all 3 cakes with a share of 33.33%) were used as a base for obtaining biopolymer films. The film forming solution (10% w/v) was adjusted to pH 12, heated to 90 0C, and filtered. The films were obtained by the casting method and dried under ambient conditions. Mechanical characteristics (tensile strength and elongation at break) and physico-chemical characteristics (moisture content, solubility and swelling)

were examined on the obtained films. The results showed that the most significant influence was the type of the applied cake on the examined characteristics, followed by cake`s share in the film forming solution.

Keywords: *oil cakes, comsposition, edible films, properties*

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MODELLING AND OPTIMIZATION OF ANTIMICROBIAL ACTIVITY OF PULLULAN FILM INCORPORATED WITH CITRIC ACID

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Pullulan is an extracellular water-soluble homopolysaccharide produced by Aureobasidium pullulans (Singh et al., 2012). It is often described as a linear polymer of -(16)-linked maltotriose subunits (Mitic et al., 2009). Due to its exceptional film-forming characteristics, pullulan's application as a food packaging material has increased in recent years. Pullulan films have several advantages over other polysaccharides, such as being colorless, odorless, tasteless, transparent, and heat-sealable. They can also function as an oil and oxygen barrier. Using pullulan as a packaging material is also quite safe for the environment (Pınar et al., 2013; Ponnusami et al., 2015). The objective of this study was to develop a citric acid and glycerol-based antimicrobial pullulan film and optimize its antibacterial characteristics. The Response Surface Methodology was used to investigate the effect of pullulan (X1; g/100 mL), citric acid (X2; g/100 mL), and glycerol (X3; g/100 mL) concentrations on the antibacterial activity of pullulan films integrated with citric acid (Pul-CA films) against Echerichia coli ATCC 25922 and Salmonella enteritidis. Pul-CA films were characterized according to their thickness, apparent surface color, moisture content, mechanical properties, water vapor permeability, scanning electron microscopy, uv-visible absorption properties, and Fourier transform infrared spectrum. The optimum conditions for antimicrobial activity of Pul-CA film were determined as; pullulan concentration: 5.42 g/100 mL, citric acid concentration: 9.61 g/100 mL, and glycerol concentration: 1.5 g/100 mL. The estimated inhibition zone area of E. coli ATCC 25922 (Y1) and S. enteritidis (Y2) in optimum conditions were 390.0±14.98 and 385.6±17.69 mm2, respectively. As a result of confirmation experiments, the observed value of Y1 and Y2 were 392.61 and 450 mm2, respectively. The optimization process caused an increase antimicrobial activity of Pul-CA film. According to the the author's

knowledge, for the first time in the literature, citric acid-integrated pullulan film was prepared, and the antimicrobial activity of this film was optimized.

Keywords: *pullulan, antibacterial, film, citric acid, optimization*

MULTILAYER MONOMATERIAL ACTIVE PACKAGING MATERIALS

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The design and preparation of multilayer packaging materials made from single polymer is important in order to overcome the main problem in recycling of multilayer packaging. Today, all multilayer packaging is made of the layers of various polymers. It is very often quite different by nature and properties, which are hard to separate and recycle, thus these packaging materials turn into packaging waste. Using a single type of polymer for all layers would be a better and wiser choice for recycling since the whole material can degrade under defined conditions; particularly, if the polymer is biodegradable like poly(lactide), poly(hydroxyl alcanoate), cellulose or starch. This concept is in accordance with not only the circular and bio-economy, but also the current directives and strategies suggested by the United Nations and the European Union such as Sustainable Development Goals and EU Green Deal.

Employing diverse technologies for the production of the layers enables different structuring of materials with superior properties. The main goals are to achieve synergetic effect of different inner layered structures and to maximize the impact of i) versatile technologies, and ii) active compounds in order to propose new concept of circular plastic packaging.

In our research, poly(lactide) "PLA" is processed with different techniques including solution casting, extrusion and electrospinning. For the purpose of the production of the active layer, it is necessary that PLA to be loaded with different natural active compounds derived from plants or industrial waste streams, with antioxidant and/or antimicrobial activity. As it is already known, PLA itself has some drawbacks in thermal and mechanical properties, as well in gas-barrier properties, thus single layer PLA is not a packaging material of choice when strive for circular packaging. Another problem with the PLA films

produced by extrusion is incorporation of natural active components, which are thermo sensitive and very hard to be efficiently encapsulated into polymer without activity loss. However, it is possible to overcome these PLA-related issues by electospinning of PLA-based solutions containing active components. Hence, electrospun nanofibers have many advantages in terms of good properties and activity, and in combination with another material they can improve barrier properties. Additionally, the activity of electrospun materials is much higher in comparison with the traditional films, even with lower concentrations of active components.

Keywords: *PLA, active packaging, electrospinning, multilayer, monomaterial*

COMPREHENSIVE BIBLIOMETRIC REVIEW ON ACTIVE PACKAGING

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This study presents a bibliometric review of scientific publications on active packaging. The Bibliometrix R package and Biblioshiny interface were utilized to analyze 2123 English language, Science Citation Index Expanded documents published in Web of Science database before 2022. The first source on active packaging was published in 1986, and the field gained immense popularity for the last few years with annual scientific publication over 18%. The core group consisted of nine out of 309 journals with Food Packaging and Shelf Life (138 documents), followed by International Journal of Macromolecules (118 documents) being most active in the area. Brazil and Spain made the highest contribution on the field followed by China, Iran, Italy and USA. The multiple countries publication ratio was in general lower than single country publication on active packaging. Collaboration network analysis was conducted to display associations between top countries and institutions on the area, which resulted in six distinct country and institution collaboration networks. One of these groups consisted of Spain, Italy, Brazil, Portugal, Argentina, Chile, Colombia, Mexico, Romania, Algeria and Slovenia with Spain having the highest collaboration with the rest of the group members. The most frequent keywords mapped with the word cloud were shelf life and edible films, other notable words were antioxidant, chitosan, antimicrobial activity, barrier properties, essential oils, etc. Evolutionary nuances of active packaging domain at different time periods were explored. Active packaging and alpha-tocopherol were the only research topics during the first period which branched to various fields over time. Recent trending research topics were antimicrobial, essential oils, nanocomposites, etc. The objective of this study is to explore development trends in journal performance, collaboration patterns, intellectual structure and time-dependent co-evolution of research sub-branches of active packaging field by performing descriptive and retrospective bibliometric analysis.

Keywords: *bibliometrix, network analysis, performance analysis, science mapping*

PLA-PHA BLENDS: BIODEGRADATION, MORPHOLOGY, MECHANICAL AND THERMAL PROPERTIES

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Biobased polymers polylactides (PLA) and polyhydroxyalkanoates (PHA) are alternatives to petroleum-based polymers and represent a circular and sustainable solution. The biobased polymers often have serious drawbacks compared to conventional petroleum-based polymers. One is poor toughness of PLA which limit its practical applications. Blending of PLA with PHA is a useful way to create new blends with improved properties, which can overcome the poor toughness of neat PLA. The thermal and mechanical properties, morphology and biodegradability of PLA/PHA blends can be tuned by choosing the proper polymers and varying the composition of the blend.

PLA and amorphous PHA copolymer were compounded in a laboratory extruder. Mixtures with different ratios of PLA and PHA were prepared without the addition of a compatibilizer. Pure PLA as reference and PLA/PHA blends were processed by cast extrusion. Films with a thickness of 20 µm to 50 µm and a width of about 220 mm were produced. The properties of the prepared films depend on the PHA content of the blend. The influence of the addition of an amorphous PHA copolymer to the PLA/PHA blend on the mechanical properties, biodegradability and morphology was investigated. The correlation of stiffness, strength and elongation at break with the kinetics of crystallisation of PLA in PLA/PHA blends, and the biodegradation behaviour as a function of the kinetics of crystallisation of PLA in PLA/PHA blends are presented in this paper. The mechanical properties of the prepared films were characterised in the extrusion direction and transverse to the extrusion direction. The different degree of crystallinity of PLA in PLA/PHA blends affects the transparency of the prepared

films. Tests were carried out with 10 wt.% and 20 wt.% PHA blends. The low PHA content in the blends was due to the high price of PHA compared to PLA.

The results suggest that PLA/PHA blend films could also be used for packaging films, since the toughness of PLA/PHA blend films was much higher than that of pure PLA and thus comparable to that of films extruded from recycled polyethylene.

Keywords: *PLA, PHA, extrusion, biodegradation, toughness*

BIODEGRADABILITY AND MOLECULAR DOCKING STUDIES OF LIGNIN/PLA COMPOSITES FOR FOOD PACKAGING APPLICATIONS

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PLA is a bio-based poly ester-derived polymer and is majorly obtained from corn starch and used in packaging applications. Due to its limited thermal and mechanical properties, lignin has been added as a filler at various weight percentages (1%, 5%, 10%, 20%, and 40%) to produce functional biobased material for food packaging. Based on our comprehensive previous studies, 5% of lignin with PLA showed an excellent performance in terms of physical, mechanical, antioxidant, and migration properties. However, focusing on the end-of-life scenario, biodegradation is the fundamental parameter to consider for sustainable composites for enhancing the circular economy. PLA emits greenhouse gases like methane and changes the soil pH to acidic when disposes to landfills. The biodegradation of PLA/lignin using natural microorganisms and its enzymes plays an important role and also such a process is an eco-friendly way to boost the degradation efficiently. It is commonly known that the laccase enzyme presents in the Trametes Versicolor is capable to biodegrade the lignin polymer. We have studied the biodegradation of the composites using Trametes Versicolor fungi and their performance was evaluated through weight loss before and after the experiment. The surface morphology of the sample before and after degradation test were analysed using KEYENCE VHX-6000 digital microscope. The obtained results and the enzyme efficiency were compared to the molecular docking study. The molecular docking simulation study was performed using Autodock vina software. Fungal enzymes were retrieved from the protein data bank and considered the active laccase for Trametes Versicolor, 1KYA, and the binding energy, and binding affinity of the enzyme with PLA and lignin were investigated. Dimensions of binding sites in the enzyme cavity with the PLA and lignin were calculated. This study is

expected to provide a broad view of PLA/Lignin bio composite degradation in fungal media.

Keywords: *lignin, PLA, biodegradation, fungi enzyme, molecular docking*

VALORIZATION OF POTATO CHIPS BY-PRODUCTS BY THE BLOWN EXTRUSION OF BIOPLASTICS FOR FRUIT PRESERVATION

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Starch-rich washing slurries and oil-rich residues are largely produced and wasted by potato chips companies. To value these by-products, water tolerant and flexible bioplastics have been developed [1]. On the other hand, a large amount of fruit is lost worldwide due to their delicate nature and short shelf-life, thus requiring packaging materials able to minimize this global problem, while ensuring the fruit quality and safety [2]. In this work, targeting to develop an eco-friendly material, starch and oil recovered from potato washing slurries and frying residues were blend with PBAT and blown extruded as a biodegradable film. Physicochemical, water/oxygen barrier, and mechanical properties of the starch/oil/PBAT-based film as well as its suitability to preserve banana were studied. A non-biodegradable polyester multilayer-based film was used as control.

Bananas packaged with the starch/oil/PBAT-based film presented a higher firmness (11.5 ± 2.3 N) and less intense brownish coloration (L = 51 ± 17, a= 5 ± 2, and b* = 34 ± 16) than those packaged with the multilayer non-biodegradable film (5.7 ± 1.0 N, L = 42 ± 11, a*= 7 ± 3, and b*= 26 ± 9, respectively). The banana packaging with starch/oil/PBAT-based film had an increased weight loss (up to 15%) than the one with the non-biodegradable film, however, no water condensation was observed in starch/oil/PBAT-based packaging contrary to what happened in those with non-biodegradable film on top. Therefore, so far this study points towards the benefits of using the starch/oil/PBAT-based film on banana preservation, offering a new sustainable*

strategy for the valorization of potato chips by-products and the fruit packaging sector.

Keywords: *starch, blow extrusion, by-products, fruit, packaging*

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MULTIPLE RECYCLING OF PLA - INFLUENCE ON THE COLOR CHANGE AND MECHANICAL PROPERTIES

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Poly(lactide) (PLA) is the most common biobased and biodegradable polyester with a variety of applications for both high-performance and high-volume products. It is very suitable for applications in the packaging industry, since it can be processed on the existing process equipment with small modifications. Also, it can be modified to meet the requirements of the packed products regarding the gas permeability, mechanical and thermal properties. It is thoroughly examined through the years, and large scale production is established. One of the reasons why it was the material of choice for the food packaging industry was it's biodegradability, since most of the food packaging is single-use and in most of the cases it is thrown away and finishes on the landfill. But, the biodegradability of the PLA is not so fast nor possible in all environments, but only under controlled conditions in industrial composters. For this reason, PLA should be properly collected and degraded under appropriate conditions, but still only a limited amount of polymers is allowed in the compost bin. Also, degradation of the materials should be the last step of the materials cycle, not the first, since the raw materials and energy are embedded into it and it would be better to recycle it instead of degrade it.

In this paper, the influence of multiple recycling of the PLA industrial waste on mechanical and sensorial properties was examined. Industrial waste PLA bottles were provided from the Slovenian company Stramex PET. The bottles undergo milling and extrusion, and then 10 cycles of injection molding followed by milling. The color of the samples evolved from transparent to slightly opaque when comparing the first and the last series of samples, which is not a drawback since this material will be processed into very thin packaging films. Melt flow rate was increasing with the number of the cycles of reprocessing,

which was expected since the slight degradation of PLA occured due to the mechanical and thermal treatments. Tensile properties, flexural and impact strength were slightly decreasing through the series for the same reason. Overall, the difference between first and tenth cycle samples is not so significant, and it can be considered that PLA can undergo at least 10 cycles of thermo-mechanical recycling.

Keywords: *poly(lactide), recycling, sensory characteristics, mechanical properties*

POLYSACCHARIDES-BASED BIONANOCOMPOSITES AS ACTIVE FOOD PACKAGING

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The development of sustainable food packaging materials with active properties is of growing interest to extend the shelf-life and/or retarding the deterioration of food, contributing to reduce food waste. In this context, polysaccharides have been exploited to develop edible and biodegradable films due to their functional and sustainable characteristics. Furthermore, the incorporation of fillers has been a strategy to ensure the mechanical and gas barrier characteristics required for food packaging, to compete with synthetic polymers, while provide the bioactive properties.

In this work, the combination of different fillers, namely graphene derivatives, clays, and zinc oxide, to design new formulations based on polysaccharides (starch, alginate and chitosan) allow to produce biomaterials with enhanced mechanical and barrier properties, conferring functional properties as antioxidant capacity, antimicrobial activity and/or electrical conductivity [1-4]. Electrical conductivity is a required property for the processing of food at low temperature using electric fields. The pulsed electric field (PEF) is a non-thermal food processing technique that preserves the nutritional and organoleptic food properties, meeting the high demand for minimally processed food. Currently the food is processed into a treatment chamber before packaging, which represents a risk of recontamination. The use of an electrically conductive food packaging to sterilize food in-pack may overcome this drawback. This strategy represents an excellent way to enlarge the biobased film properties for food packaging application, thus being biodegradable and renewable alternatives to replace the petroleum-based plastics. Therefore, these bionanocomposites have a great potential as innovative and active food packaging.

Keywords: *starch, alginate, chitosan, zinc oxide, graphene*

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BIO-BASED LIGHTWEIGHT PACKAGING MATERIALS THROUGH EXTRUSION FOAMING

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Increasing use of plastics and amount of packaging waste are some of the key challenges to be solved in future decades. In addition, there is a growing need to find alternatives for fossil-based plastics in various applications including packaging. There is a clear need to decrease the amount of materials used in packages. One way to do this is to use extrusion foaming, which allows creation of lightweight materials. In extrusion foaming it is also possible to use different polymers and the interest is naturally towards bio-based, biodegradable polymers. This presentation will present the potential of extrusion foaming in creation of future packaging materials. Furthermore, the presentation will discuss about different material options to be used in the process.

Keywords: *bio-based material, biopolymer, extrusion foaming, packaging*

COEXTRUDED FILMS BASED ON BIODEGRADABLE BLENDS FOR MULTI-FUNCTIONAL FOOD PACKAGING

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The use of biodegradable polymers for packaging applications represent an effective strategy to reduce the environmental impact of fossil-based plastics. Among them, poly(L-lactic acid) (PLA), poly(butylene succinate) (PBS) and poly(butylene-adipate-co-terephthalate) (PBAT) are known for their good degradability. PLA stands out for its good mechanical, optical and rheological properties; however, it is fragile and has limited thermal and impact resistance. On its side, PBS has good toughness, excellent elongation and impact resistance, as well as good thermal and chemical resistance; nevertheless, the poor resistance to thermal sealing limits its use as a packaging material. Finally, PBAT is known for its very high ductility and flexibility, even at low temperatures, while its poor stiffness, low transparency and low seal strength have so far limited its use.

Therefore, it is necessary to implement appropriate functionalization strategies with the purpose of expanding the application field of biodegradable plastics. In this regard, the realization of multilayer films based on blends of biodegradable polymers couples two promising approaches to combine biopolymers having complementary bulk properties; the final functional performance of the films can be modulated by controlling the mixing ratio and the molecular characteristics of the components, as well as the relative thickness and position of the layers.

In this research, coextruded films based on blends of biodegradable polymers were designed and realized in order to have:

• An inner layer combining good ductility, both at ambient and low temperatures, good sealability and tear resistance; with this purpose, blends at

different mass ratios of amorphous PLA and PBAT were tested:
• An external layer with good gas barrier properties and good thermal resistance; with this purpose, blends of PBS and semicrystalline PLA at different mass ratios were tested.

Blown films were produced by a laboratory scale co-extrusion plant, obtaining different configurations by varying the blends composition and the relative thicknesses of the layers.

The systems were characterized by several techniques (DSC, FTIR spectroscopy, surface wettability and adhesion, tensile tests at 25 °C and -18 °C, oxygen permeability, optical properties, hot tack tests) to evaluate the thermal, chemical and functional performance of the films. Hot filling measurements and migration tests were also performed to investigate films thermal resistance and suitability for food packaging applications.

The results showed that the approach pursued was successful in developing innovative, eco-sustainable films having multiple functional performance through a technique commonly used in the packaging industry. The produced films showed good interlayer adhesion, with a good control of the relative thicknesses during the co-extrusion process and overall migration values lower than the limits established by the legislation. The PBAT/PLA inner layer, at its optimized composition, was effective in providing good ductility and sealability function within an extended temperature range commonly used for food packaging.

The PBS/PLA outer layer, at its optimized composition, was effective in decreasing the oxygen permeation in multilayer configurations (up to 57% with respect to the single inner layer), in providing excellent thermal resistance and hot tack force with respect to the neat inner layer.

Keywords: *multilayer films, biodegradable blends, polylactic acid (PLA), multifunctional packaging, co-extrusion*

PRODUCTION AND PROPERTIES OF BIODEGRADABLE PBAT FILMS FOR FRUITS AND VEGETABLE PACKAGING: A COMPARISON BETWEEN SCIENTIFIC LITERATURE AND COMMERCIAL SPECIFICATIONS

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As the global use of plastic continues to rise[1], it becomes crucial to explore different possibilities of waste management[2]. One potential solution is to replace traditional plastics with biodegradable polymers, in some applications. One such application is as bags for short-term holding of fruits and vegetables and PBAT-based materials are selected by many supermarkets. Polybutylene adipate-co-terephthalate (PBAT) is a random copolymer originating from petrochemical, which is biodegradable. PBAT stiffness increases with the terephthalate content and its tensile strength increases with molecular weight. These properties can be tailored according to their use[2]. To improve properties and reduce the cost blends with other polymers and compatible fillers have been studied. On addition of thermoplastic starch (TPS), a blend with higher Young's modulus is obtained[3]. PBAT blended with PLA has improved mechanical properties[4]. Due to the poor miscibility of PBAT and PLA, many compatibilizers have been studied[2]. Incorporating innovative ingredients such as coffee pods[5], essential oil[6] and more have been explored.

In this study, PBAT pellets were formulated and used to produce films via solvent casting. Chemical and physical characteristics were compared with the addition of glucose-based fillers like as nanocellulose (NC) and starch. This setup was applied for several different concentrations, 1-2% for NC and 5-25% for starch. The films were characterized regarding moisture barrier, colour, FTIR spectra and thermal transitions by differential scanning calorimetry. The

outcome was compared with those materials commercially available for fruits and vegetable packages. A critical review and a comparative study with the data provided in the literature were performed, focusing on mechanical and barrier properties, physical characteristics and biodegradability performance. The difference between properties of films industrially prepared and laboratory-made was highlighted indicating the major gap between end-users expectations based on the laboratory results and performance of materials available for real-case applications.

Keywords: *biodegradable packaging, PBAT, fruits and vegetables, starch, nanocellulose*

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SEQUENTIAL PARTICLE SIZE REDUCTION OF LIGNIN AND ITS IMPLEMENTATION AS A WATER RESISTANT BIOCOATING IN PAPER PACKAGING

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Paper-based packaging materials have poor mechanical and water vapor barrier properties that are required a treatment such as coating to produce water resistant, mechanically integral materials. Because the use of paper in food packaging as a sustainable solution is favored, the novel approaches and investigations are highly needed. Lignin, the second most abundant natural polymer, has emerged as a potential alternative material to petroleum-based chemicals and renewable resource for bio-based material production.

In this study, lignin particle size was reduced using a sequential ultrasonication and alkali treatment. Commercial alkali lignin (0.1 wt.%) was used in order to obtain sub-micron lignin particles and the changes in the size and zeta potential of obtained particles were determined by zetasizer (Malvern Nano ZS). The size of water dispersed lignin particles (55.06±0.54 µm) was reduced to 877±86 nm by a sonotrode-type ultrasonication (UP200S, Hielscher/Germany, sonotrode S7 with 0.5 cycles and 50% amplitude) for 60 min and further reduced to 369±45 nm upon the alkali treatment by NaOH (1N, pH 12). Consumed energy after ultrasonication step was recorded to be 360 J per ml of lignin solution in order for us to reproduce same size regardless of sonotrode type and sonication time. The selected lignin particles were then used to coat grass fiber-based paperboard. For this purpose, the selected lignin particles and chitosan film-forming solution was applied on paperboard in the layer-by-layer structure upon the several cycles of surface treatment by corona ion charger. The surface free energy and water contact angle values confirmed that lignin particle-containing coating layers were more hydrophobic. This increased hydrophobicity was validated with water sorption analysis.

These results revealed that the green combined protocol of top down ultranocation approach with alkali treatment for the size reduction lignin was solvent free and suitable forvalue-added lignin particles intended for hydrophobic paper coatings. Due to the multipurpose nature of the layer-by-layer assembly, there is great potential for the utilization of lignin as sustainable multifunctional films including a wide variety of applications such as UV-protective coatings, antimicrobial materials, and composites, glue, Pickering emulsions, drug delivery, and wound healing.

Keywords: *lignin particles, sequential size reduction, biocoating, ultrasonication, paper packaging*

STUDYING CRANBERRY EXTRACT FILMS WITH ENHANCED ANTIMICROBIAL PROPERTIES AS AN ALTERNATIVE FOR FOOD PACKAGING

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In some countries, cranberries are over-produced and that may lead spoilage. Thus, if other applications are encountered for this issue, the excess of production may follow other routes and decrease waste.

In this study the potential of cranberry extract as a valuable antibiofilm additive of chitosan-based films intended for food packaging applications was investigated. Two types of chitosan-based films differing in the plasticizer content (PEG alone or PEG and glycerol) were prepared by solvent casting methodology. Cranberry-extracts used presented antioxidant properties (i.e. DPPH scavenging ability) and antimicrobial activity (towards Escherichia coli ATCC 25922 and Staphylococcus aureus ATCC 25923). Additionally, among phenolic compounds present, responsible for those activities were isorhamnetin-3-glucoside, hydroxybenzoic acid, phloridzin, pelargonidin, chlorogenic acid, epicatechin and A-type procyanidin that were identified by HPLC-MS/MS. Films incorporating cranberry extracts presented suitable food preservation characteristics (light transmission, water and oxygen permeability). Those films were also able to quench DPPH radical by 92.2 ± 3.9 (PEG added) and 89.7 ± 0.7 % (PEG and glycerol added) and inhibit E. coli and S. aureus biofilm formation. Concerning E. coli, a reduction of 5 and 4 log units

was obtained with films added of PEG or PEG/glycerol, respectively. Remarkably, both chitosan-films completely prevented S. aureus biofilm. The obtained results place cranberry-chitosan films as a potential option for food packaging with antioxidant and antibiofilm properties as added value.

Keywords: *chitosan-films, antioxidant; antimicrobial; active-food-packaging; cranberry*

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IMPROVING COLD-CHAIN MANAGEMENT OF PERISHABLE PRODUCTS THROUGH TEMPERATURE MONITORING BY INTELLIGENT PACKAGING

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Almost a third of all the food produced globally is wasted every year and half of perishable produce is lost due to lack of or inadequate access to cold-chain logistics. Temperature monitoring of perishable products in cold-chain is becoming more and more important. Monitoring temperature helps build reliable solutions within the whole cold-chain, keeping the quality and safety of a product, enhance customer satisfaction and can contribute to prevention of food waste. Especially important segments are: chilled food (2–14°C), such as meat, fish, diary and fruits; and frozen food (about −18 °C). Another segment, which can benefit from temperature monitoring is pharmaceutical industry.

Monitoring temperature can be done through fixed sensors. They provide monitoring of an environment in a production, warehouses, transportation vehicles and other storing facilities. By introducing the IoT, the data can be easily stored in databases, collectively evaluated and visualised. Since the sensor is not mounted on the product's packaging, some "blind" spots may occur, especially in the case the chain is broken. To tackle this problem, an intelligent label can be added to the primary or secondary packaging.

This paper aims to present a short review of temperature indicators and discuss their potential in future intelligent packaging solutions.

Smart label can be based on RFID or NFC technology. The tag must contain an antenna and a sensor, that can be both made by conventional printing techniques. The information is collected by a reading device. Active RFID tags additionally contain battery and chips for storing the data. The usage of RFID

tags is a challenging process, especially when the antenna/chip has to be separated from the plastic/paper substrate in the recycling processes.

However, there are more simple and sustainable ways of tracking temperature changes. So called temperature and time-temperature smart labels, which change their colour if the product was heated above given threshold. Several time-temperature indicators have been reported in literature and are already available on the market. The colour change is based on chemically induced colour change or a signal fluid spreading through a diffusive layer. In both cases, a rate of reaction or diffusion is driven by temperature and time. These indicators are applied to the primary package of the product and have to be mechanically or optically activated. Some solutions offer more spatially demanding indicators with a pocket that releases active material after breaking. Other indicators are in form of thin labels. Their advantage lies in capability to be printable by conventional printing techniques, which allow arbitrary design of an indicator, less demanding requirements for recyclability of packaging and more sustainable solutions for intelligent packaging applications.

Keywords: *intelligent packaging, cold-chain, thermochromic, indicator, temperature monitoring*

EFFECTS OF NANOMATERIAL REINFORCED FIBROUS CASING OF SUGARCANE BAGASSE ON THE ADSORPTION OF POLYCYCLIC AROMATIC HYDROCARBONS (PAHS) IN SMOKED SAUSAGES

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Novel nanocomposites containing nano-carbon and nano-clay nanoparticles (0.5 and 1% wt.) were developed to evaluate the adsorption effects of 4 carcinogenic polyaromatic hydrocarbons (PAH4, benzo[a]anthracene, Chrysene, benzo[b]fluoranthene, and benzo[a]pyrene) during the smoking process of sausages. The mechanical, water vapor permeability (WVP), film opacity, thermal properties, morphology, and the adsorption efficiency of produced films were assessed. It was observed that both nano-carbon and nano-lay additions to the film formulation led to significant improvement in tensile strength, elongation at break, maximum load stress, and elastic modulus values compared to control film. The WVP of the films was significantly reduced by the addition of nanoparticles. Film opacity, melting temperature, crystallization temperature, crystallinity degree, and glass transition temperature were remarkably increased. These improvements were more highlighted when nano-clay nanoparticles (1% wt.) were used compared to nano-carbon. The nano-clay nanocomposite indicated uniform and well-distributed nanoparticles. Based on the GC-MS analysis, nanocomposite nanoparticles efficiently adsorbed the PAH4 compared to control and nanocomposite film with nano-carbon nanoparticles.

Keywords: *fibrous film; nano-clay and nano-carbon; PAHs; adsorption; mechanical properties*

OLIVE POMACE WASTE AS AN ALTERNATIVE NON-WOOD PULP SOURCE FOR SUSTAINABLE FOOD PACKAGING APPLICATIONS

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Background: Olive pomace, by being one of the olive oil processing wastes, mainly composed of cellulose, lignin, and hemicellulose as well as fat and proteins coming from skin, kernel, stone, and pulp of olive. Olive pomace waste disposal without any treatment causes several environmental problems in a very short period as olives are processed seasonally to produce olive oil. Therefore, after recovery of pomace oil, the remaining waste (olive pomace) should be managed properly in a short span of time. Besides, agro-industrial wastes such as olive pomace can be considered a potential candidate to be used as raw material for pulp production.

Aim: This study aims to determine the potential use of olive pomace remained after pomace oil recovery as molded pulp material, which can be used as a secondary packaging material for food products.

Method: Olive pomace was firstly treated with hot water at 130°C for 30 min to remove hemicellulose and then pulped by cooking with NaOH (5, 7, and 10%, w/w) at 130°C for 30 min or 1 h (with/without anthraquinone at a concentration of 0.1%, w/w). The obtained pulps were molded into sheets after bleaching with 5% hypochlorite (pomace/hypochlorite, 1/5, w/w) at 60°C for 24 h. The pulps were also molded without bleaching treatment to determine the effectiveness of NaOH treatment itself as a bleaching step. The hemicellulose and lignin content of olive pomace before and after hot water treatment was determined. The morphological properties of the selected molded pulps were determined by scanning electron microscopy (SEM) and Fourier Transform Infrared spectroscopy (FTIR) analysis. The density and grammage of obtained molded pulps were also measured to evaluate their suitability for commercial applications.

Results: The molded pulps prepared using 10% NaOH in the presence of anthraquinone showed better performance for packaging use due to its higher cellulose content leading to a high degree of fiber bonds. Molded pulps prepared using 5% NaOH without anthraquinone could not form a proper sheet after pressing, which might be related to the weak fiber network and unsuccessful entanglement between the fibers.

Conclusion: Nevertheless, to produce highly efficient pulps with the potential use of all agricultural wastes as alternative pulp materials, the properties of sub-standard pulps made of wastes should be improved. This study revealed that the properties of non-wood pulps made from olive pomace wastes could be enhanced for further use.

Keywords: *olive pomace, non-wood pulp, waste utilization, sustainable food packaging*

ELECTROSPUN FIBROUS EDIBLE MATERIALS FOR FOOD PACKAGING APPLICATIONS

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The aim of the study is to obtain homogeneous micro size edible fibers membranes of polyvinyl alcohol (PVA) and propolis by the electrospinning method and to evaluate their suitability for food packaging. Three propolis extracts (Pext.) are used in the study – water, alcoholic, and glycerin-based. Chemical structure, morphology and fiber diameter distribution, air permeability, tensile stress-strain characteristics at distinct relative humidity levels, thermal stability, and microbial properties of electrospun PVA/Pext. webs are analyzed.

As a result of the applied electrospinning procedure, propolis-containing PVA membranes with randomly oriented microfibers have been obtained, the addition of propolis increases the fiber diameters from 277 nm to 985 nm. Concomitant tensile strength of obtained electrospun PVA/Pext. webs may reach 7 MPa and more, depending on the thickness of the web, relative moisture content, and composition of the material. In its turn, the highest ultimate elongation at break values (around 380 %) of the investigated PVA/Pext. webs are in the case of glycerin-based additive. Glycerin additive demonstrated also a positive influence on the thermal stability of Pext. itself and Pext. PVA/Pext. webs. The air permeability of a 1 µm thick electrospun fiber membrane is in the range of 0.001 to 0.008 l/min and decreases with increasing the thickness of the membrane.

In general, it is expected, that depending on composition as well as manufacturing conditions, certain formulations of electrospun membranes may find applications as perspective environmentally friendly materials with

improved mechanical, thermal, and antimicrobial properties for manufacturing of not only sustainable food packaging, but also gas filtering elements and membranes in biomedicine.

Keywords: *edible food packaging, electrospun fibers*

EFFECT OF BIOCHAR ON MECHANICAL, THERMAL, AND HYGROSCOPIC PROPERTIES OF HEMP-POLYLACTIC ACID (PLA) COMPOSITES AND BIODEGRADATION BEHAVIORS UNDER FUNGI ACTIVITY

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Plastic materials are commonly used in packaging due to their low cost and favorable properties. In fact, it was estimated that 66% of the world's plastic wastes are derived from packaging applications and are mainly composed of petroleum derived polymers such as polyethylene. To alleviate the negative environmental impact, biodegradable packaging can be used.

Interest in polymeric composites reinforced by natural fibers has increased due to their high strength, lower weight, and renewability. For instance, polylactic acid (PLA) has demonstrated distinctive features such as composability, transparency, rigidity, and processability [1]. Nonetheless, PLA use is limited by its high degree of crystallization and inherent brittleness [2], as well as its relatively low glass transition temperature that negatively affects thermal resistance. Reinforcement of PLA with natural fibers can enhance the resulting mechanical and thermal properties [2]. In particular, hemp fibers were reported as a potential effective reinforcement in PLA that showed improved mechanical and thermal features [3]. However, the currently high price of PLA, and other shortcomings such as moisture resistance and biodegradability remain key challenges that has limited the use of hemp/PLA composites.

Biochar is an interesting candidate to both reduce price and improve the performances of hemp/PLA composites. Biochar is a carbon rich material derived from biomass pyrolysis at high temperature and oxygen free atmosphere [4]. Biochar was reported to significantly improve tensile strength of composites [5].

In this study, we investigated the effect of biochar addition on the properties of hemp/PLA composites. Samples were prepared by blending PLA with hemp fibers (0 and 30 wt%) and biochar (0, 5, 10, and 20 wt%) followed by injection molding. The influence of biochar on the mechanical properties, thermal stability, and water repellency of the resulting composites was studied. Moreover, the biodegradation of the tested composites under effect of Fomitopsis betulina and Trametes versicolor fungi is tracked for five months, and biodegradation behaviors will be presented.

Keywords: *biochar, polylactic acid, hemp fibers, mechanical properties, thermal stability*

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NEW PHYSICAL PE/PP COMPATIBILIZERS FROM TRI-BLOCK COPOLYMERS

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The European parliament's new EU directive (UE) 2019/904 sets a number of milestones to be achieved in the use of plastics. Of these milestones, we highlight the need for recollection of 90% of plastic residues for recycling by 2029. These residues must be reprocessed and reused, either in the same application or in a different application than that of the material from which they originally came. When plastics arrive in bales at a circular economy facility, the sorting system cannot remove 100% of some contaminants. In streams of polyethylene (PE), the most critical contaminant is polypropylene (PP). PE and PP are immiscible polymers and, due to their chemical similarities, it is very difficult to separate them in an effective way. The contaminants which remain in the recycled pellets are known to make the extrusion process unstable, resulting in a higher amount of discarded plastic. One of the solutions to this problem is the development of compatibilizers, of which there are two types: reactive (which chemically link the polymers together) or non-reactive (which only render the two polymers miscible, by physical interactions).

Here, we present a series of new physical compatibilizers for polyolefin recycling lines. These are tri-block copolymers consisting of an amorphous mid-block, sided by two semi-crystalline blocks. These were synthesized via Atom transfer radical polymerization (ATRP).

The main advantage of this technique is the possibility to use non-toxic solvents, liquid monomers and readily available catalysts, while maintaining the controlled structure of the resulting polymers.

We have used three different polymerization initiators, and have successfully obtained compatibilizer polymers, with different structures. The catalytic system and the solvents are currently being optimized, for large-scale production.

The synthesized polymers were tested in the Post-Consumer Recycling (PCR) process line at Silvex. The resulting pellets were extruded in a blown film lab scale extruder, and the film was fully characterized for tensile strength, elongation, Dart Drop resistance, and appearance. The compatibilization capability of the new copolymers was evaluated through industrial scale testing, and Scanning Electron Microscopy (SEM). The success of the compatibilization will be measured after three extrusion/recycling cycles.

Keywords: *recycling, circular economy, polyolefins, compatibilizers, block copolymers*

SUSTAINABLE AND ELECTRICALLY CONDUCTIVE BIOCOMPOSITES FOR FUNCTIONAL FOOD PACKAGING

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Pulsed electric field (PEF) is an emerging and promising food processing technology. The non-thermal food sterilization preserves the nutritional and organoleptic food properties, meeting the high demand for minimally processed food. The PEF sterilization is currently performed before the packaging process, which is associated with extra costs and the risk of recontamination.[1] The PEF in-pack would prevent these drawbacks and foster the industrial PEF implementation. However, an adequate electrically conductive food packing material is thus required. Biopolymer-based electrically conductive biocomposites are promising materials for this application. Herein, eco-friendly biocomposite films containing chitosan as matrix and reduced graphene oxide (rGO) as filler were prepared.[2] rGO was hydrothermally synthesized in presence of caffeic acid.[3] The biocomposites containing 0–50% rGO were prepared by solvent casting. The structure and morphology of the films were characterized by X-Ray Diffraction (XRD), Raman spectroscopy, Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM) and Conductive AFM (CAFM). The electrical conductivity, mechanical

properties, water solubility and antioxidant activity were also investigated. The XRD diffractograms presented the characteristic signature of chitosan and rGO, whereas the Raman spectra showed the characteristic bands of graphitic materials. SEM images showed a good dispersion of rGO through the chitosan matrix. The AFM and CAFM, acquired simultaneously, allowed the mapping of the rGO distribution at the nanoscale, being the origin of the surface roughness and electrical current. The tensile strength and Young's modulus increased with the incorporation of rGO into the chitosan matrix, while the elongation at break decreased, which means that the films became more resistant but less flexible. The water solubility of chitosan films decreased by the incorporation of rGO due to the hydrophobic nature of rGO. The chitosan film containing 50% rGO revealed antioxidant activity able to inhibit the ABTS.+ up to 82% in 8 h. The maximum electrical conductivity of 0.7 S/m was achieved by this film in-plane direction, while the film containing 45% rGO achieved a maximum of 2.1 x 10-5 S/m through-plane direction. The electrically conductive biocomposites, with reinforced mechanical properties, water resistance and antioxidant activity can be applied as food packaging electrodes to sterilize food by PEF in-pack.

Keywords: *electrically conductive biocomposite, chitosan, reduced graphene oxide, pulsed electric field*

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ASSESSING WATER PERMEABILITY PROPERTIES OF CHITOSAN AND WHEY PROTEIN CONCENTRATE COMPOSITE EDIBLE FILMS WITH NANOCRYSTAL CELLULOSE FROM CORN PLANT INCORPORATION

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Growing concerns about petroleum-based plastic contributing greatly to pollution have led researchers to new, durable, and biodegradable materials with good film properties. Approximately 80% of waste plastic belongs to food packaging, and the ratio has been tended to increase in the near future. Biodegradable films have been studied for more than a decade, and there were many study results, including what are the advantages and blindsides of the films on the application of food packaging. Although they offer a good solution in terms of plastic waste pollution, some features that food packaging should show, such as good barrier properties and durability have not been adequately achieved with biodegradable films. Protein (i.e. whey protein) and carbohydrate (i.e. chitosan) mixtures that is named as hydrogels for its hydrophilicity and gelation ability, are preferred materials for biodegradable films. However, such materials are unstable and can therefore be affected by many different conditions such as relative humidity or temperature of environment. Therefore, they need to be reinforced in terms of both barrier and mechanical properties. There are various chemicals used for this purpose, such as graphene which is known for good mechanical properties. However, some reports say these substances have some toxic effects. For these reasons, in our study, the whey protein concentrate (>80% protein) and chitosan composite films (WPC-CTS) were prepared using grape seed extract as cross linking agent (CLA) which required for formation of hydrogels. In addition, nanocrystalline

cellulose (NCC) was included in the formulation in order to improve the mechanical properties. NCC was obtained by using the parts of the corn plant (except the cob) which is a waste and most preferred as animal feed. The water vapor permeabilities (WVP) of NCC reinforced films was investigated to understand the effect of NCC on WVP at various concentration (0.1, 0.3 and 0.5%). The WVPs of the films were calculated as 1.80, 1.08, 1.57 g mm m−2 h−1 kPa−1 for films having 0.1, 0.3 and 0.5% NCC, respectively. The differences in WVP found to be insignificant, while mechanical properties improved. The further assessment NCC on film properties has been continued within the scope of project supported by the Coordination Unit of Scientific Research Projects (BAP) of Adana Alparslan Türkeş University (project number 20103006).

Keywords: *edible film, reinforcement, nanocrystalline cellulose, mechanical and barrier properties*

ALTERNATIVE SOURCE OF GREEN PACKAGING MATERIAL

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Recently, biopolymers have played a critical role in resolving environmental problems created by plastics, particularly. Biodegradable materials, such as seaweed-based films and coatings, are becoming increasingly popular for use in food packaging and as active carriers of ingredients. Seaweeds that have a lot of polysaccharides are considered commercially important because they can be used in so many different ways in industry. In the food industry, seaweed-based polysaccharides such as agar, carrageenan, alginate, and cellulose have a wide range of applications, some of which use as an emulsifier, gelation agent, stabilizator, and other similar properties. They can be found in large quantities, have a favourable cost, renewability and sustainability. The degradability, antioxidant and antimicrobial properties, non-toxicity, and good film-forming of seaweed polysaccharides have spurred interest in the fabrication of packaging materials in recent years. Seaweed polysaccharide appears to have promise as a food contact material, further research and development are needed before it can be commercially viable in the markets. Seaweed-based films have been characterized using a scanning electron microscope (SEM), Fourier transform infrared spectroscopy (FTIR), physicochemical, and mechanical properties. Total phenolic content and DPPH radical scavenging capacity assay showed that seaweed-based biopolymer film showed higher antioxidant properties than control film. The study has indicated that seaweed could be a possible alternative source for attempting to make bioplastics, which could reduce the use of plastics that are non-degradable.

Keywords: *seaweed, biodegradable film, active film, mechanical properties*

PLA-PET BLENDS: PREPATARION AND MECHANICAL RECYCLING

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Bio-based and bio-degradable polymers like polylactides (PLA) represent more sustainable solution due to their end of life and low carbon footprint thus may be used as alternatives to petroleum-based polymers in different applications. However, with biopolymers there are often certain drawbacks compared to conventional petroleum-based polymers, such as low toughness of PLA and poorer thermal performance which limit their practical applications. Blending of recycled PLA with recycled polyethylene terephthalate (PET) is a useful way to create new blends with improved properties, while simplifying the separation of waste bottle material, since PLA along with PET are among most used materials by consumption in bottle manufacture.

In present work, PLA bottles were ground and mixed with ground PET followed by compounding in a laboratory twin screw extruder. Three mixtures with different ratios 95/5, 90/10 and 85/15 of PLA/PET were prepared without the addition of a compatibilizer. Further, PLA/PET blends were processed by injection moulding. Injection moulded specimen of sizes according to ISO 527 (type 1BA), ISO 178 and ISO 179 standards were ground, and injection moulded again. Mechanical recycling was repeated 10 times. Thermal, mechanical, and optical properties were evaluated after 1st, 3rd, 5th, 7th, and 10th cycle of injection moulding.

The results suggest that addition of PET in PLA improves thermal stability of the materials. Mechanical and optical properties do not decrease dramatically even after 10 cycles of mechanical recycling, which indicates the potential of material as a sustainable option in broad range of applications.

Keywords: *PLA, PET, mechanical recycling, recyclate, blends*

CHARACTERISATION OF BLEND FILMS BASED ON MICROBIAL POLYSACCHARIDE LEVAN AND GELATIN

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Food packaging ensures safety and hygiene, while reducing food waste, therefore it is and essential component of the food supply chain. A sustainable and biodegradable alternative to conventional food packaging is edible packaging which contributes to the reducing waste and the economic efficiency of packaging materials [1]. The numerous biopolymeric materials could be used as source such as polysaccharides (starch, cellulose, chitosan) and proteins (gelatin, soy protein, whey). Exopolysaccharides (EPS) are fermentation-based biopolymers, secreted outside the cell wall and synthesized by various microbial species including bacteria, fungi and blue-green algae [2]. Microbial levan is fructose-based EPS and convenient due to its biocompatibility, renewability, high molecular weight, low viscous nature, antioxidant and prebiotic effects [3].

Levan used in this work was produced by the B. licheniformis NS032 strain [4] and its hydrophobic derivatives were obtained using octenyl succinic anhydride (OSA). Degree of substitution (DS) for modified levans were 0.025 and 0.032 for LH22 and LH26 respectively. Three different film compositions were prepared: levan/LH22/LH26 with gelatin in proportions 1:1. Films were prepared by casting technique and evaporated at room temperature. Morphology of the obtained films were studied by AFM (Atomic force microscopy), AutoProbe CP-Research SPM (TM Microscopes-Bruker) and mechanical properties were examined by Shimadzu EZ-LX tensile tester.

The samples had thickness of 150 µm. Based on morphological measurements, it can be concluded that use of levan derivatives change roughness of the

levan/gelatin blend film. The best mechanical properties (tensile strength and elongation at break) were obtained with pure levan. Obtained films are composed from edible and biodegradable components and therefore are potentially applicable in food industry. Future investigation will be focused on optimization of levan/gelatin proportion and more extensive structural and mechanical properties of obtained films.

Keywords: *edible packaging, exopolysaccharides, levan, gelatin*

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EDIBLE PACKAGING MATERIALS: CAN WE EAT THE FOOD WITH ITS PACKAGE?

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In light of this continuous momentum of manufacturers of packaging materials in the search for natural raw materials to produce environmentally friendly packaging. Edible packages have gained great attention in this regard, because they are edible in addition to being sustainable (biodegradable, and/or compostable), as they are made from materials of biological origin (vegetable sources) as well as their use as active packages. Having this in mind, a new generation of edible packages is being developed that include additional functional properties by incorporating natural active compounds with antimicrobial, antioxidant, or enzymic properties. Combining these active compounds will not only protect foods from spoilage and extend their shelf life but also improve the physical and chemical properties of the packages. More work remains to improve the functionality of the edible packages to achieve appropriate applications in foods. This interest has reflected positively on market expectations, according to the Allied Market Research website which predicts a growth in the market value of edible packaging materials from $697 million in 2016 to $1,097 million in 2023. However, some challenges limiting the expanded use of edible packages are believed to be overcome with more research efforts. Among these challenges: 1) What is related to the industrial aspect, where inedible materials enter in varying proportions during the manufacture of edible packages, which eliminates some of the environmental benefits. 2) What is related to the technological characteristics of edible packages, as it is more sensitive to temperature that may cause problems during the transportation process. 3) What is related to the psychological aspect of consumers, as consumers will need time to shift their culture from the culture of discarding packages to the culture of eating them. Therefore, all predictions indicate that the pace of development and modernization in the

edible packaging industry is increasing rapidly, in order to achieve the desired luxury.

Keywords: *edible packaging materials, sustainability, functionality*

MORPHOLOGY OF ZINC OXIDE NANOPARTICLES: EFFECT ON FUNCTIONAL ACTIVITY AND PERFORMANCE FOR APPLICATION IN BIONANOCOMPOSITES FOR FOOD PACKAGING

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The consumer's continuous demand for food with natural quality, safe, minimally processed, and with extended shelf-life and the concern with environmental impact are driving the use of bio-based materials in food packaging. The application of nanotechnology in food packaging enhances material properties, such as barrier to gases, thermal and light stability, and mechanical strength, offering active and intelligent functionalities that assure protection and preservation.

Zinc oxide (ZnO) is currently found in mainly daily life applications. It has received a positive safety evaluation from European Food Safety Authority (EFSA) for packaging applications as transparent ultraviolet light (UV) absorbers on the basis of an absence of a significant migration in particulate form. It also is considered GRAS (Generally Recognized as Safe) by the Food and Drug Administration (FDA). Zinc oxide nanoparticles (ZnO NP) are also known to have good antimicrobial properties and therefore are suitable to be applied as active compounds. Despite the abundant literature addressing the use of ZnO NP as antimicrobial component in packaging materials, the effect of particles size and morphology on the activity against different microorganisms is still poorly studied.

This project aimed at developing ZnO NP with different shapes (spherical, rod and flower), and sizes and studying the impact on the antioxidant and antimicrobial activities of the materials where the particles have been incorporated. The ZnO NP were produced by different methods: hydrothermal, solvothermal, microwave radiation, ball milling and sol-gel. A green synthesis approach with pumpkin seed extracted has been tested in order to create a sustainable route. ZnO NPs were characterized by powder X-ray diffractometer (XRD), Fourier transform infrared spectroscopy (FT-IR), UV-visible spectroscopy (UV–vis), Scanning electron microscopy coupled to energy-dispersive X-ray spectroscopy (SEM/EDS), Electron paramagnetic resonance (EPR) and nitrogen adsorption-desorption isotherms. Zinc quantification was performed by atomic absorption spectroscopy (AAS). All the results were compared with commercial ZnO NP.

The sol-gel method was found to be the most suitable to control the shape and sizes of the ZnO NP. The following control parameters were optimised for each shape: solvent, precursor, and physicochemical settings such as temperature and pH. Spherical NP were obtained with 80-95 nm, rod shape with length of 100-130 nm and width of 50-60 nm, and flower shape were obtained with length of 650-800 nm and diameter of 450-550 nm. The antimicrobial activity was evaluated by the agar diffusion assay and viable cell count (spiral plate), showing that the particles with different morphologic characteristics render different functional performance.

This is to be correlated with particles surface specific area and with the migration behaviour after incorporation in the packaging material.

Keywords: *zinc oxide, antimicrobial activity, nanoparticles shape, packaging films*

MULTIFUNCTIONAL PROPERTIES OF PBAT WITH HEMP MICRONIZED PARTICLES/FIBERS FOR FOOD PACKAGING

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"Hemp stalks is considered one important by-product of the hemp industry. Recently, the interest in cannabis derivations has increased in Portugal where the well-valued fibers are cultivated in good conditions.

Hemp has an interesting concentration in cellulose and the fibre has high strength, and Young's modulus, when compared with other plants [1], as well good bioactivity, thanks to its composition in cannabinoids, alkanoids, lignin among others, which makes it attractive to food packaging [2].

Polybutylene Adipate Terephthalate (PBAT) and its blends and composites are promising biodegradable polymers, due to their mechanical properties and good resistance to water when compared to other biopolymers. PBAT is used in packaging and agricultural films, also as compost bags. Recently, researchers focused on the improvement of PBAT properties by the incorporation of organic and inorganic components into the films [3].

In the present work, films of PBAT with hemp micronized particles/fibers were produced by solvent casting. Characterization of the hemp microparticles/fibers was made using different spectroscopic techniques. The content in cellulose, hemicellulose and lignin was estimated using a chemical process and the thermal stability was evaluated by monitoring the weight loss from 25-500 ºC. The chemical composition was evaluated by GC-MS with injection by head-space, SPME, and after liquid extraction. The morphology of the particles and of the films was analyzed by SEM. The films water vapor

*permeability (WVP) and the chromatic properties (colorimeter L*ab values and RGB calculation) were studied.*

The results indicated the hemp particles have the main loss (≈ 97%) between 100-200 ºC with a significant color change from beige to black ash. In coherence, the increase of temperature from 200 to 500 ºC demonstrated changes in the FTIR bands confirming the degradation of hemp components. Interestingly, the incorporation of hemp into the PBAT films decreased the WVP, leading to better barrier properties. The chemical composition by chromatographic screening highlights the presence of many essential oil compounds responsible for its high medicinal profile and contributing to its antimicrobial properties: 2-cyclohexene-1-one, Y-sitosterol, 2,6-Dimethoxyhydroquinone and others that have already been explored for their antimicrobial properties such as oxazolidine, maltol, piperonal, eugenol, humulene oxide II and trans-caryophyllene to list a few. Furthermore, hemp influenced the mechanical and antibacterial properties of PBAT. The biodegradability of the films was evaluated in a compost bin.

Keywords: *hemp, PBAT, biodegradability, antibacterial, food packaging*

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DESIGN OF POLYMER COMPOSITES BASED ON NATURAL FIBERS AS PACKAGING MATERIALS

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The interest in natural fiber-reinforced polymer composites is growing rapidly due to their high performance in terms of mechanical properties, significant processing advantages, excellent chemical resistance, low cost and low density. In this lecture, the compression and injection molding of polypropylene (PP) and polylactic acid (PLA) based composites reinforced with rice hulls or kenaf fibres will be presented and their basic properties will be discussed. Rice hulls from rice processing plants and natural lignocellulosic kenaf fibres from the bast of the plant Hibiscus Cannabinus represent renewable sources that could be utilized for composites. Maleic anhydride grafted PP (MAPP) and maleic anhydride grafted PLA (MAPLA) were used as coupling agents (CA) to improve the compatibility and adhesion between the fibres and the matrix. Investigations of the possibilities for reuse of the polymer eco-composites have been carried out. The eco-composites based on recycled matrices and recycled composites were produced and structure/properties relationships were investigated as a function of the number of reprocessing cycles. As a result of comparison of the composites properties, the polymer eco-composites belong in the category of materials which could be used as fibre-based packaging materials for different industries.

Keywords: *polypropylene, polylactic acid, composites, rice hulls, kenaf fibres*

VALORISATION OF COFFEE BYPRODUCTS-DERIVED PECTIC POLYSACCHARIDES BY THE DEVELOPMENT OF ACTIVE BIOPLASTICS AND PAPER COATINGS

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Agrifood industry byproducts are worldwide generated and often discarded, implying the waste of valuable biomolecules. Under a circular economy, polysaccharide-rich agrifood byproducts have been used in the development of active bioplastics [1,2]. On the other hand, paper-based packages are usually coated with non-biodegradable petroleum-based polymers, compromising their biodegradability and recyclability. To overcome this drawback, biobased paper coatings have been developed [3]. In this work, the feasibility of using coffee fruit cascara (CFC), a coffee processing byproduct, to develop bioplastic formulations suitable for paper coating was evaluated. CFC polysaccharide rich-derived extracts were obtained by a microwave-assisted extraction (MAE) and compared with the ones obtained by a conventional hot-water extraction (HWE).

MAE increased in ca. 25% the HWE yield of water-soluble CFC fractions enriched in pectic polysaccharides (40-50 molar % GalA). When processed by solvent casting, formulations containing high molecular weight CFC-derived extracts (2.75% w/v) allowed to develop transparent brownish bioplastics with

hydrophilic (water contact angle ca. 29°), flexible (Young's modulus ca. 272 MPa; elongation at break ca. 4%), and antioxidant profile (50% ABTS•+ inhibition after 5 min). When applied as paper coating, the CFC-derived extracts (20% w/v, viscosity ca. 154 cP) conferred a brownish coloration to the neat paper and increased its basis weight in 6 g/m2 and its thickness in 9 µm, while increasing the paper flexibility. Moreover, after only 24 h of immersion into distilled water, 4% of the CFC-coating weight was leached out, demonstrating the easy recyclability of CFC-coated papers. Therefore, CFC revealed to be a natural source of pectic polysaccharides suitable for developing antioxidant bioplastics and paper coatings, opening an opportunity to minimize the ecological footprint of agricultural, plastic, and paper sectors.

Keywords: *cascara, bioplastic, coating, antioxidant, circular economy*

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POTATO CHIPS BYPRODUCTS FOR ACTIVE STARCH-BASED FILMS DEVELOPMENT

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Potato chips industry gives rise to byproducts, such as starch-rich washing slurries and brownish frying residues, that have simply been landfilled, increasing its ecological footprint. These byproducts can be valued as a source of biomolecules, such as polysaccharides and high-molecular weight brown color compounds (melanoidins), with potential to develop active biobased materials, following circular and sustainable concepts. In this work, the brownish-derived extract (BrE) and starch, both recovered from potato chips processing, were in-situ gelatinized to form potato starch-based films. Different BrE amounts (5%, 10%, and 15% w/w of dry starch weight) were tested. The incorporation of BrE conferred a yellowish coloration to the transparent starch-based films and improved ca. 2x the traction resistance and elasticity of the films. Their wettability increased ca. 15º and 20º the water contact angles at the upper and down films surface, as well as their antioxidant activity (ca. 94% of ABTS •+ inhibition in 4 h). Besides, as high the BrE amount, lower the solubility in water (from 12% in the pristine to almost 0% in films containing 15% of BrE) and higher the UV-A and UV-C radiation absorption capacity of the BrE/starch-based films. In turn, BrE reveals to contain molecules of interest that allowed to tune the performance of potato starch-based films, offering a new strategy to valorize potato chips industry byproducts.

Keywords: *potato chips, starch films, byproducts*

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SCREENING OF VOLATILE ORGANIC COMPOUNDS EMITTED FROM DIFFERENT PACKAGING MATERIALS: CASE STUDY ON FRESH-CUT ARTICHOKES

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In the present work, the emission of volatile organic compounds (VOCs) from plastic packages in contact with food and their presence in/on food was investigated. Based on previous results on fresh-cut artichokes as case study, microperforated polypropylene (PP), polypropylene/polyamide (PP/PA) and polylactic acid (PLA) were selected as package materials. MA-packaged fresh-cut artichokes were stored for 6 days at 5° C. For the detection of VOCs on the plastic materials, two approaches were considered. First, a 2.5x2.5 cm package squared piece was cut, inserted into a SPME vial and conditioned at 30°C for 10 min. VOCs emitted from the package were then extracted by a DVB/CAR/PDMS solid phase microextraction (SPME) fiber for 20 min, at 30°C, and analysed by gas-chromatography coupled to mass spectrometry (GC-MS). An empty vial was used as control. Second, a DVB/CAR/PDMS SPME fiber was used to extract volatile compounds for 30 min, at 5°C, from the whole bag headspace, to understand if any package volatile compound was transferred into the package atmosphere in this temperature condition. Finally, artichokes were also analysed by SPME/GC-MS to detect any presence of package volatiles. Emitted VOCs, were different according to the material; in particular PP/PA emitted the greatest amount of VOCs, most of them belonging to the class of branched alkanes, such as 4-methyl-heptane, 2,4-dimethyl-heptane, 4-methyl-octane; PP emitted heptanal, propanoic acid, acetic acid;PLA emitted acetic and propanoic acids. PP/PA VOCs were found also into the atmosphere of the PP bags with and without fresh-cut artichokes. Furthermore, most of the plastic-related VOCs were detected also on packaged products, while they were not found in fresh artichokes, suggesting that a study on the emission of VOCs from different

plastic materials in contact with food and on the effect of different storage conditions is very critical for a better understanding of this issue.

Keywords: *package, volatile organic compounds, gas-chromatography-mass spectrometry*

AGRO RESIDUES AS POTENTIAL BARRIER ENHANCER FOR FIBRE-BASED FOOD PACKAGING

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As wood-based derivatives are under pressure due to $C0_2$ sequestration and other uses (biomass), agro and industrial residues are starting to be promising sources of the feedstocks for different applications in the food industry, as well other low and high added value applications. The use of brans and husks as typical side stream products generated during processing of different grains into flour generate overstocks, which are not useful for long term storage due to fermentation. One of their uses are typical as feedstock for animals or mixed food products as cereals. Recently there have been initiatives for using these side streams in packaging materials. Based on chemical composition the hemicellulose and fatty acid derivatives have shown good grease and water vapor barriers. Modified xylan hemicellulose was also found to be a good starting material for coating and barrier applications. The grease barrier for packaging solutions could be achieved with coating in combination with bio-polymers or on the other hand with incorporation of the hemicellulose rich residues in the paper matrix as fillers In the presented research, three different agro residues (spelt husk and two wheat brans) with high content of hemicellulose were incorporated in the paper matrix as fillers to improve the fat and oil barriers of the papers. The agro residues were delignified with the Kraft process and laboratory hand sheets were produced. To test the barrier properties of the bran and husk laboratory sheet materials we have done the water vapor test, KIT test on oil and grease barrier as well the ultrasound dynamic water absorption test and contact angle testing. To test the possibility of converting the materials with thermoforming and sealing we have done the DSC and TGA characterization of the samples. The results show very good properties for the wheat bran samples with very low water absorption and water vapor barriers (140-150 g/m^2*24h), as well as an excellent KIT test with

*values of 12. The sample of the semolina husk had lower values for all measured properties (530 g/m^2*24h, KIT test 1). The thermal characterization of the samples also shows potential for processing with further optimization needed which will be researched in the future food packaging applications.*

Keywords: *agro residue brans and husks, barrier properties, thermal characterization*

IDENTIFICATION OF HEALTH AND SUSTAINABILITY ELEMENTS IN FOOD LABELING

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This proposal aims to provide a solution to the social need to achieve a "Healthy and Sustainable" food system, in which, in addition to aspects of human health, the concept of sustainability is considered with three dimensions, such as the social, economic and environmental circumstances of each society. This work has the specific objective of facilitate an adequate food choice based on its nutritional value and considering elements of sustainability in food packaging.

The current food system faces the challenge of meeting the needs to feed a world population of 9.7 billion by 2050. To date, established dietary patterns have not been shown to achieve the goal of maintaining good health in the entire population. Therefore, the evolution of the current food system towards a more sustainable and environmentally friendly food model is essential. Until now, "healthy" and "environmentally friendly" have rarely been considered together, in terms of public health campaigns, in product marketing campaigns, and in research examining the effectiveness of these interventions. Although consumers may state that they find aspects such as "healthiness" and "environmental friendliness" to be important factors in purchasing food products, this acclaimed interest does not necessarily translate into consumption behaviour. Consumers have difficulty understanding food labeling that shows a mix of mandatory and voluntary information, making it challenging to understand sustainability aspects.

Food labeling is closely related to food safety and is the main communication channel between food producers and consumers. This is because, as Regulation (EU) No. 1169/2011 itself indicates, labeling is no longer just a mere graphic description of the food and its composition, but rather it is considered to provide food information to the consumer. For this reason, Regulation (EC) Nº

1924/2006 regulates the nutritional and health claims that may appear on food labels, and other related legislative provisions. Regarding the use of environmental declarations, terms such as organic, biological, and ecological are strictly regulated by Regulation (EU) 2018/848, which has been improved to meet the high expectations that consumers have of organic production and clarifies the current legislative procedure.

The "United Nations Decade of Action on Nutrition", a commitment established by all United Nations member states implements different policies and programs that integrate, in the concept of diet, the two dimensions of health and sustainability. It is intended to comply with some of the Sustainable Development Goals (SDG), specifically 2,3,4 and 12, in relation to food. Therefore, this work is related to those 2030 Agenda SDGs directly linked to food and health, in addition to education.

This work can offer direct and accessible help to citizens, not only providing knowledge, but preventing misinformation or false beliefs that so easily reach the consumer through the media. The choice of food and diet becomes a scenario of responsibility, given the important implications that food consumption has for both, health and the environment.

Keywords: *sustainability, health, food labeling, service-learning*