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O presente número da Millenium - Journal of Education, Technologies, and Health apresenta artigos em 3 áreas fundamentais das ciências da educação, agrárias e da gestão.

Na área da educação, apresenta-se o artigo "Como as teorias da educação podem ser aplicadas no ensino da contabilidade" que faz a ligação entre o ensino da contabilidade e as diferentes teorias da educação que nele podem ser aplicados. É um tema muito atraente e atual para todos aqueles que ensinam ou estudam Contabilidade, mas também muito interessante para qualquer pedagogo. No texto, o ensino da Contabilidade é analisado, tendo por base as teorias do behaviorismo, humanismo, cognitivismo, cognitivismo social e construtivismo.

No que se refere às ciências agrárias, podem ser apreciados seis artigos de temas diversos. No artigo "Implementação do controlo estatístico do processo numa linha de engarrafamento da indústria vinícola" procura-se evidenciar a influência que a implementação desse mesmo controlo estatístico (através da implementação SPC) tem na melhoria da qualidade do produto final; o artigo "Efeito da adição de culturas de arranque nas propriedades físico-químicas e sensoriais da alheira de vitela" demonstra a possibilidade da utilização da cultura de L. plantarum ST153Ch no armazenamento do produto até pelo menos 75 dias; o artigo intitulado "Influência da temperatura de estufa na composição química de um malte de cevada grego e suas propriedades de mosto" apresenta um estudo que evidencia a importância da otimização da temperatura de estufa para aumentar a qualidade do malte e do mosto; o artigo "Avaliação sensorial da carne de suínos machos inteiros criados com diferentes condições de alimentação e alojamento" desenvolve uma avaliação das características organoléticas da carne de porcos machos não castrados com o objetivo de reduzir ou eliminar o odor a varrasco. Finalmente, no artigo "O efeito da maltagem sobre os cristalitos e microestrutura no cultivar de cevada grega usando difratometria de raios X e análise microscópica", apresenta-se um estudo acerca do impacto da maltagem na morfologia dos grânulos de amido da variedade Seiros da cevada.

Por último, destacamos os três artigos inseridos na área da gestão. O primeiro apresenta um estudo acerca do "Comportamento elasto-plástico ao corte de estruturas favos-de-mel e auxéticas reforçadas", no qual se conclui que, embora a transformação auxética promova um aumento do módulo de corte, gera deformações plásticas a valores mais baixos. O artigo "Aplicação web para análise de teste de avaliação", na área das aplicações desenvolvidas na internet com o objetivo de analisar testes de avaliação, apresenta a aplicação web Evaluate como ferramenta para a análise de testes de aferição, evidenciando o seu papel na identificação de inconsistências dos testes e permitindo a inserção de melhorias. O terceiro artigo "Acessibilidade, património e projeto. Re-arquiteturas para todos" é dedicado ao estudo da arquitetura, onde se advoga que um dos aspetos mais importantes da arquitetura é a sua perceção sensorial, algo prioritário ao ser humano para valorização e satisfação com as estruturas/espaços, pelo que se a acessibilidade for considerada como um requisito desde o princípio do projeto, obtêm-se melhores soluções arquitetónicas.

A multidisciplinariedade patente nos artigos no número 7 da Revista reafirmam a mais valia e a essência da divulgação da investigação científica.

A Equipa Editorial
Madalena Cunha, José Luís Abrantes, Maria João Amante, Paula Correia, Paula Santos

This issue of Millenium - Journal of Education, Technologies, and Health presents articles in three main areas of science: education, agriculture and business management.

The article entitled "How learning theories can be applied in accounting education" is presented in the area of education, which links the teaching of accounting to the different theories of education that can be applied to it. It is a very popular and current theme not only for all those who teach or study Accounting, but also for educators in general. The teaching of Accounting is analyzed in this paper and is based on theories of behaviorism, humanism, cognitivism, social cognitivism and constructivism.

As far as the agricultural sciences are concerned, there are six articles on a variety of subjects. The article, "Implementation of statistical process control in a bottling line in the winery industry", shows the influence that the implementation of the same statistical control (through the SPC implementation) has on the improvement of the quality of the final product. The following article entitled "Effect of addition of a starter cultures on physicochemical and sensory properties of "alheira", a smoked sausage-like product" demonstrates the possibility of using L. plantarum ST153Ch culture when storing the product for at least 75 days. "Influence of kilning temperature on chemical composition of a greek barley malt and its wort properties" is the next paper which presents a study that highlights the importance of the kilning temperature optimization to increase the quality of malt and must. "Sensory evaluation of meat from entire male pigs raised with different feeding and housing conditions" is the name of the subsequent article which focuses on the development of an evaluation of the organoleptic characteristics of the meat of uncastrated male pigs in order to reduce or eliminate boar taint. Finally, the article "The effect of malting on the crystallites and microstructure in Greek barley cultivar using x-ray diffraction and microscopic analysis", is a study on the impact of the malting on the morphology of the starch granules of Seiros, a variety of barley.

Finally, we highlight the three articles from the area of business management. The first one presents a study about "Elasto-plastic shear behavior of reinforced honeycomb and auxetic reentrant lattices", which concluded that although the auxetic transformation promotes an increase of the cutting module, it generates plastic defects at a lower cost. The article "Web application for the analysis of assessment tests", in the area of web applications developed with the purpose to analyse assessment tests, presents Evaluate, a web application, used as a tool for the analysis of benchmarking tests, accentuating its role in identifying test inconsistencies and allowing improvements to be made. The third article "Accessibility, heritage, and project. re-architectures for everyone" is dedicated to the study of architecture. The authors argue that one of the most important aspects of architecture is its sensorial perception, which is considered a priority for human beings for appreciation and satisfaction of structures/spaces, whereby if accessibility is considered a requirement from the outset of the project, better architectural solutions are obtained.

Multidisciplinarity is well substantiated in the articles of issue 7 of this Journal, which only confirm the added value and the essence of the dissemination of scientific research.

The Editorial Board
Madalena Cunha, José Luís Abrantes, Maria João Amante, Paula Correia, Paula Santos

El presente número de Millenium - Journal of Education, Technologies, and Health presenta artículos en 3 áreas fundamentales de las ciencias de la educación, las agrarias y la gestión.

En el área de la educación, se presenta el artículo "Como las teorías de la educación se pueden aplicar en la enseñanza de la contabilidad" que hace la conexión entre la enseñanza de la contabilidad y las diferentes teorías de la educación que en él pueden ser aplicadas. Es un tema muy atractivo y actual para todos aquellos que enseñan o estudian Contabilidad, pero también muy interesante para cualquier pedagogo. En el texto, la enseñanza de la Contabilidad es analizada, teniendo como base las teorías del conductismo, humanismo, cognitivismo, cognitivismo social y constructivismo.

En lo que se refiere a las ciencias agrarias, se pueden apreciar seis artículos de temas diversos. En el artículo "Implementación del control estadístico del proceso en una línea de engarrafamento en la industria vinícola" se busca evidenciar la influencia que la implementación de ese mismo control estadístico (a través de la implementación SPC) tiene en la mejora de la calidad del producto final; el artículo "Efecto de la adición de cultivos iniciadores sobre las propiedades fisicoquímicas y sensoriales de "alheira", un embutido ahumado", un embutido ahumado" Demuestra la posibilidad de la utilización del cultivo de L. plantarum ST153Ch en el almacenamiento del producto hasta por lo menos 75 días; el artículo titulado "La influencia de la temperatura de secado en la composición química de una malta de cebada griega y las propiedades de su mosto" presenta un estudio que evidencia la importancia de la optimización de la temperatura de estufa para aumentar la calidad de la malta y del mosto; "Evaluación sensorial de la carne de cerdos machos enteros criados con diferentes condiciones de alimentación y alojamiento" desarrolla una evaluación de las características organolépticas de la carne de cerdos machos no castrados con el objetivo de reducir o eliminar el olor a verraco. Finalmente, en el artículo "El efecto del malteado sobre los cristalitos y la microestructura en el cultivo de una cebada griega usando difracción de rayos x y análisis microscópico" se presenta un estudio sobre el impacto del malteado en la morfología de los gránulos de almidón de la variedad Seiros de la cebada.

Por último, destacamos los tres artículos incluidos en el área de la gestión. El primero presenta un estudio sobre el "Comportamiento elasto-plástico al cizalladura de estructuras panal y augéticas reforzadas", en el cual se concluye que, aunque la transformación augética promueve un aumento del módulo de corte, genera deformaciones plásticas a valores más bajos. El artículo "Aplicación web para análisis de pruebas de evaluación" en el área de las aplicaciones desarrolladas en Internet con el objetivo de analizar pruebas de evaluación, presenta la aplicación web Evaluate como una herramienta para el análisis de pruebas de evaluación, evidenciando su papel en la identificación de inconsistencias de las pruebas y permitiendo la inserción de mejoras. El tercer artículo "Accesibilidad, patrimonio y proyecto. re-architectures para todos" es dedicado al estudio de la arquitectura, donde se aboga que uno de los aspectos más importantes de la arquitectura es su percepción sensorial, algo prioritario al ser humano para valorización y satisfacción con las estructuras/espacios, por lo que si la accesibilidad se considera como un requisito desde el principio del proyecto, se obtienen mejores soluciones arquitectónicas.

La multidisciplinariedad patente en los artículos en el número 7 de la Revista reafirma la plusvalía y la esencia de la divulgación de la investigación científica.

El Equipo Editorial
Madalena Cunha, José Luís Abrantes, Maria João Amante, Paula Correia, Paula Santos

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COMO AS TEORIAS DA EDUCAÇÃO PODEM SER APLICADAS NO ENSINO DA CONTABILIDADE

HOW LEARNING THEORIES CAN BE APPLIED IN ACCOUNTING EDUCATION

COMO LAS TEORÍAS DE LA EDUCACIÓN SE PUEDEN APLICAR EN LA ENSEÑANZA DE LA CONTABILIDAD

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RESUMO

Introdução: Possuir competências técnicas não é suficiente para ser um bom formador em contabilidade. O conhecimento sobre as teorias da aprendizagem, os métodos de aprendizagem, as diferentes formas de avaliação de conhecimento, os diferentes métodos de ensino, é também fundamental para ser um bom formador em contabilidade.
Objetivos: Analisar as teorias de aprendizagem que podem ser aplicadas no ensino da contabilidade e como podem ajudar os formadores de contabilidade a melhorar o processo de aprendizagem de acordo com as suas competências.
Métodos: Revisão da literatura sobre as competências dos profissionais de contabilidade e análise da aplicação das teorias de aprendizagem no ensino da contabilidade.
Resultados: Tendo por base algumas teorias de aprendizagem (behaviorismo, humanismo, cognitivismo, cognitivismo social e construtivismo), proporcionar um conjunto de recomendações aos formadores em contabilidade de modo a melhorar o processo de aprendizagem.
Conclusões: Mesmo que um formador disponha de uma boa formação académica, uma larga experiência profissional; mesmo que use tecnologias de ensino inovadoras, se o formador não escutar os formandos; se o formador não perceber que cada formando apresenta uma formação de base diferente, uma cultura diferente, uma forma diferente de aprender; se o formador não perceber que não existe uma forma standard de ensinar, o formador não será bem sucedido.

Palavras-chave: Ensino de contabilidade; Competências em contabilidade; Teorias de aprendizagem; Estilos de aprendizagem; Educação de adultos.

ABSTRACT

Introduction: Having expertise in accounting is not enough to be an effective accounting educator. Knowledge about learning theories, learning styles, different types of assessment, and the variety of available teaching methods, is also fundamental to be a good accounting educator.
Objectives: Analyse which learning theories can be applied in accounting education and how they can help accounting educators to improve the learning process according with their competences.
Methods: Literature review about the professional accountant competencies and analysis of the learning theories application in accounting education.
Results: Based on certain learning theories (behaviourism, humanism, cognitivism, social cognitivism, and constructivism), provide a set of recommendations to accounting educators in order to improve the learning process.
Conclusions: Even if an educator has a very good academic background, and significant professional experience in the teaching area; even if he uses innovative teaching technologies, if the educator does not listen learners; if the educator does not understand that each individual learner has a different background, cultural experience and way of learning; if the educator does not understand that there is no standardized way to teach, this educator will not succeed.

Keywords: Accounting education; Accountant skills; Learning theories; Learning styles; Adult learning.

RESUMEN

Introducción: Poseer competencias técnicas no es suficiente para ser un bueno formador en contabilidad. El conocimiento sobre las teorías de aprendizaje, los métodos de aprendizaje, las distintas formas de evaluación del conocimiento, los distintos métodos de enseñanza, es también fundamental para ser un bueno formador en contabilidad.
Objetivos: Analizar las teorías de aprendizaje que pueden ser aplicadas en la enseñanza de la contabilidad y como ellas pueden ayudar los formadores de contabilidad a mejorar el proceso de aprendizaje.
Métodos: Revisión de la literatura sobre las competencias de los profesionales de contabilidad y análisis de la aplicación de las teorías de aprendizaje en la enseñanza de la contabilidad.
Resultados: Teniendo por base ciertas teorías de aprendizaje (behaviorismo, humanismo, cognitivismo, cognitivismo social y constructivismo), proporcionar un conjunto de recomendaciones a los formadores en contabilidad con el fin de mejorar el proceso de aprendizaje.
Conclusiones: Mismo que un formador disponga de una buena formación académica, una larga experiencia profesional; mismo que utilice tecnologías de enseñanza innovadoras, si el formador no escuchar los alumnos, si el formador no percibir que cada alumno presenta una formación de base distinta, una cultura distinta, una forma distinta de aprender; si el formador no percibir que no existe una forma standard de enseñar, el formador no será bien sucedido.

Palabras Clave: Enseñanza de contabilidad; Competencias en contabilidad; Teorías de aprendizaje; Estilos de aprendizaje; Educación de adultos.

INTRODUCTION

The main purpose of this article is to analyse which learning theories can be applied in accounting education and how can they help accounting educators to improve the learning process for accounting learners.

To better understand the application of learning theories in the accounting education process, first we need to have an idea about the kind of competencies a professional accountant should have. To achieve that purpose, we start by analysing the definition of accounting, highlighting as well the International Education Standards (IES) to be applied to the training and education of accountants, and by analysing the report produced by a joint task force sponsored by the Management Accounting Section (MAS) of the American Accounting Association (AAA) and the Institute of Management Accountants (IMA) with the purpose of creating a comprehensive educational framework that defines the required competencies of accounting and finance professionals.

Then, the learning theories are analysed and their application to the accounting education is discussed, followed by the characterization of learning styles and their application in accounting education, and by a brief reference to assessment methods. The article finishes with some recommendations to accounting educators in order to facilitate learning by accounting learners and with the conclusion.

1. THE REQUIRED COMPETENCIES FOR THE PROFESSIONAL ACCOUNTANTS

1.1 The definition of accounting

According with Weygandt, Kieso, Kimmel, and DeFranco (2009, p. 2), accounting "is an information system that identifies, records, and communicates the economic events of an organization to interested users". Following this definition, a professional accountant should be able to select the economic events that are relevant to a specific organization, and record them in a chronological and systematic manner. As we know, a professional accountant should follow a set of standards, usually called Generally Accepted Accounting Principles (GAAP). So, a hard skill of an accountant should be to acquire the technical knowledge about the GAAP. For example, beyond other accounting principles, to be able to prepare an Income Statement, an accountant should have the technical knowledge about the revenue recognition principle and the matching principle.

However, the definition of accounting also includes the communication of accounting information to interested users. As Weygandt et al. (2009) states, a very important element in communicating economic events is the accountant's ability to analyse and interpret the reported information, which involves explaining the uses, meaning, and limitations of the reported data. Therefore, a professional accountant should also possess some additional important soft skills, such as communication and interpersonal skills.

1.2 A good example of a framework for the accounting education

With the aim to ensure that accountants across the globe meet a minimum standard, the International Accounting Education Standards Board (IAESB) of the International Federation of Accountants (IFAC) has issued eight International Education Standards (IES) to be applied to the training and education of accountants. IES 1 establishes the entry requirements to a program of professional accounting education and initial professional development (IPD); IES 2 details the technical competence that aspiring professional accountants are required to achieve by the end of IPD; IES 3 concentrates on the needed professional skills; IES 4 requires trainee accountants to learn professional values, ethics and attitudes; IES 5 prescribes the practical experience that aspiring professional accountants are required to complete by the end of IPD; IES 6 highlights the assessment of professional capabilities and competence; IES 7 covers continuing professional development; and IES 8 covers the requirements for audit professionals (International Federation of Accountants, 2017).

Lawson, Blocher, Brewer, Gary, Sorensen, Stout, and Wouters (2014) reports the work done by a joint task force sponsored by the Management Accounting Section (MAS) of the American Accounting Association (AAA) and the Institute of Management Accountants (IMA) with the purpose of creating a comprehensive educational framework that defines the required competencies of accounting and finance professionals. According with Lawson et al. (2014, p. 296), competencies "are the set of knowledge, skills, and abilities required for professional success in accounting. Knowledge "is the intellectual content to be learned", skills are "the capacity to apply the knowledge to achieve specific goals and objectives, and abilities are the application of knowledge and skills in a professional work environment".

The authors propose four recommendations: accounting education should focus on curricular requirements for long-term career demands; the focus of accounting education should include organizational settings beyond a focus on public accounting; curriculum recommendations should derive from an analysis of how accountants add organizational value; and the competencies of accounting education should be developed within the curriculum as integrated competencies. Based on these recommendations, Lawson et al. (2014) propose an educational framework formed around three interconnected components: foundational competencies, broad management competencies, and accounting competencies. This is summarized in Figure 1.

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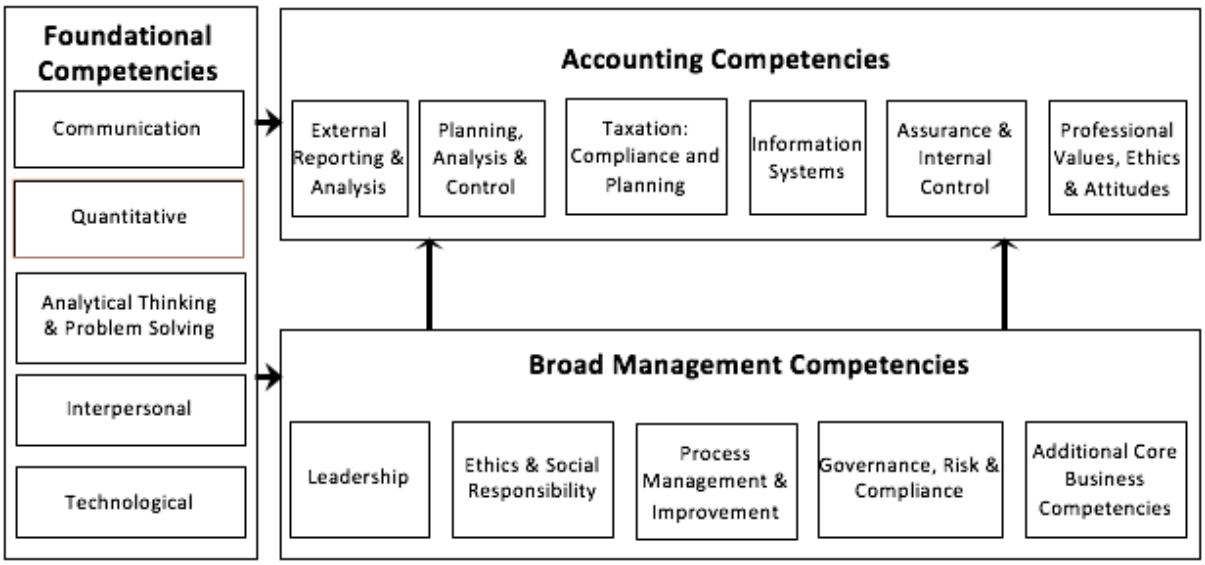

Figure 1. Competency Integration: A Framework for Accounting Education. From "Focusing Accounting Curricula on Students' Long-Run Careers: Recommendations for an Integrated Competency-Based Framework for Accounting Education", by Lawson et al., 2014, *Issues in Accounting Education, 29*(2), p. 300.

According to Lawson et al. (2014), Foundational Competencies are those that all business school graduates need to have because they support broad management and specialized accounting competencies and prepare students for life-long careers. The Accounting Competencies enable accountants to integrate management and analytical methods, supported by technology, to assist an enterprise to formulate and execute its strategy successfully. The Broad Management competencies help accountants work jointly and effectively with all members of the organization to create value, and these competencies are essential for those who aspire to become successful managers and executives.

2. THE APPLICATION OF LEARNING THEORIES, LEARNING STYLES AND DIFFERENT TYPES OF ASSESSMENT IN ACCOUNTING EDUCATION

2.1 Learning theories and accounting education

Following Merriam and Bierema (2014), there are five traditional learning theories that offer different explanations of learning: behaviourism, humanism, cognitivism, social cognitivism, and constructivism.

Introduced by Watson in the 1920s and developed into a comprehensive theory by Skinner and others, for behaviourists human behaviour is the result of the arrangement of particular stimuli in the environment. If this behaviour is reinforced or rewarded, it is likely to continue; if it is not reinforced it is likely to disappear (Merriam & Bierema, 2014). In the context of the learning process, the learner should be conditioned through punishments and rewards. Learning occurs when appropriate stimuli are presented and the learner is subsequently rewarded for exhibiting the desired behaviour. Therefore, it is the observable behaviour (and not the internal mental processes or emotional feelings) which demonstrates that learning has occurred (Merriam & Bierema, 2014).

By the 1950s, psychologists such as Maslow, had firmly established humanism as a perspective on human nature and learning (Merriam & Bierema, 2014). The main premise of humanism is that people have a natural potential for learning and that significant learning takes place when an individual can see that the subject matter is relevant to him. In this context, the educator should act as a facilitator, encouraging learning rather than identifying specific methods or techniques of instruction (Bates, 2016).

Humanistic learning theory has had a profound effect on adult learning theory. Three major adult learning theories of andragogy, self-directed learning, and transformative learning, all have roots in humanistic psychology (Merriam & Bierema, 2014). According to Knowles, andragogy is the art and science of adult learning, thus andragogy refers to any form of adult learning (Kearsley, 2010 as cited in Pappas, 2013). In 1980, Knowles made four assumptions about the characteristics of adult learners (andragogy), that are different from the assumptions about child learners (pedagogy). In 1984, Knowles added the 5th assumption (Pappas, 2013). According with Knowles (1975, p. 18), self-directed learning is "a process in which individuals take the initiative without the help of others in diagnosing their learning needs, formulating goals, identifying human and material resources, and evaluating learning outcomes".

The cognitivist theory represented a shift in the focus on learning from the environment (behaviourists), or the whole person (humanists), to the learner's mental processes (Merriam & Bierema, 2014). Cognitive theories focus on the conceptualization of

students' learning processes and address the issues of how information is received, organized, stored, and retrieved by the mind. Learning is concerned not so much with what learners do but with what they know and how they come to acquire it. The learner is viewed as a very active participant in the learning process (Ertmer & Newby, 1993).

Piaget is considered a pioneer in this area. He argued the existence of four stages of development: the sensorimotor stage, where learning takes place through touch and feel; the pre-operational stage, where the ability to arrange objects logically starts to be developed; the concrete operational stage, where the ability to think logically about objects and events starts to become more structured; and the formal operational stage, where abstract thinking and verbal reasoning start to develop (Bates, 2016).

Although Piaget's theories were developed based on his studies of children, following Bates (2016), these theories can be expanded to include people of all ages and can be summarized as follows: people react differently to learning according to their stage of cognitive development; educators should take an active, mentoring role towards their learners; learners should be encouraged to learn from their peers; learners should be allowed to learn from their mistakes; the focus should be on the process of learning as well as the outcome; educators should respect each learner's interests, abilities and limits.

The social cognitive learning theory states that much human learning occurs in a social environment:

> By observing others, people acquire knowledge, rules, skills, strategies, beliefs, and attitudes. Individuals also learn about the usefulness and appropriateness of behaviours by observing models and the consequences of modelled behaviours, and they act in accordance with their beliefs concerning the expected outcomes of actions (Schunk, 1996, as cited in Merriam & Bierema, 2014, p. 35).

Vygotsky's Social Development Theory was one of the foundations of constructivism. Vygotsky focused on the connections between people and the sociocultural context in which they act and interact in shared experiences. One of the most important milestones from Vygotsky was the concept of zone of proximal development. According to Vygotsky this is "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978, as cited in McLeod, 2012). This concept is nowadays widely used in studies about teaching and learning in many subject-matter areas (including reading, writing, mathematics, science, second-language learning, moral education), with diverse kinds of pupils (including so-called disadvantaged, learning disabled, and gifted students), with preschool children and adults, with information technologies and computer-mediated communication, with children's use of libraries, with discussions about teacher training (Chaiklin, 2003). The concept has also been picked up and used in several academic disciplines and professional areas, including nursing, psychoanalysis, psychotherapy, and occupational therapy (Chaiklin, 2003).

Like Helliar (2013) states, authors in accounting are mostly concerned on teaching: how they can teach something, or how they can manage a course to engage students, or how they can have bettered the student experience in teaching accounting, auditing or ethics. The pedagogical practices usually enhance mechanical problem solving, adopting well-structured, well-defined, and recipe-driven learning approaches that provide-"single solution" answers (Wynn-Williams, Whiting, & Adler, 2008). The presence of the behaviourist theory is quite obvious with this kind of pedagogical practices.

However, accounting education is not just about providing technical knowledge such as the double-entry bookkeeping system, or variance analysis or calculating net present values. Students may start as passive learners of the curriculum, but to be able to develop a real mastery of accounting, students need to apply concepts to solve real-life problems in different contexts (Helliar, 2013). To do that, accounting educators need to provide the scaffolding whereby students can move from a passive learning perspective to an active learning perspective.

Accounting graduates only can become successful professional accountants if they adopt the life-long learning concept, and thereby continually adapt to changes in the business environment (Hassall, Joyce, Arquero Montaño, & González González, 2010). In this context, maybe accounting educators should pay more attention not only to the behaviourist learning theory, but also to other learning theories such as humanism, cognitivism, social cognitivism, and constructivism.

2.2 Learning styles and the accounting education

Improving the teaching skills of accounting educators requires an understanding of how students learn (Fatt, 1995). Some students, for example, learn best by active participation whereas others learn best through observation. Some prefer working in groups whereas others prefer working alone. Some may prefer passive learning through lecture presentations whereas others may prefer active learning by experimenting with ideas and engaging in practical applications (Tan & Laswad, 2015).

Of all models of learning Kolb's Learning Style Instrument, which is based on experiential learning theory, is one that is well established and widely adopted in business education research (Tan & Laswad, 2015). David Kolb, inspired by the work of John Dewey, Kurt Lewin, and Jean Piaget, developed a model of experiential learning involving a four-stage cycle. Learning, according to Kolb, is a holistic process whereby knowledge is created through the transformation of experience (Duangploy & Owings, 1994). Following Chen, Jones, and Moreland (2014), the process starts when a learner finds a new experience, usually called "concrete experience" (feeling). The next phase, "reflective observation", involves drawing upon past experiences to perceive the new experience from different perspectives. Then we have the "abstract conceptualization", in which a person generates theories and solutions to the new issues encountered. Finally, the development of concepts leads to "active experimentation",

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where the person tests and applies the theories and solutions previously generated. The cycle can be continuous or repeating as individuals encounter other new experiences. According with the same authors, these dimensions of perceiving and processing information can be organized into four styles of learning: "diverging" (combine concrete experience and reflective observation), "assimilating" (combine reflective observation and abstract conceptualization), "converging" (combine abstract conceptualization and active experimentation), and "accommodating" (combine concrete experience and active experimentation).

Individuals can have different preferences associated with learning in different contexts, but most tend to default a particular style of learning. Tan and Laswad (2015) presents very good examples for each kind of learning style. For example, using the case of depreciation of fixed assets in financial accounting, a "diverger" will work through a problem with varying depreciation methods and useful lives of assets (concrete experience), then will compare the resulting effects on net income of the different depreciation expense amounts (reflective observation). For example, "convergers" can be drawn to a lecture in the framework of the accounting equation and its relevant components (abstract conceptualization), followed by the preparation of financial statements (active experimentation). An "assimilator" will prefer to work through an assignment requiring the construction of a model, for example, asking them to prepare a comprehensive master budget for a company (abstract conceptualization) and come up with relevant financial and operating budgets (reflective observation). An example of a learning structure that is appealing to "accommodators" is the case of working through profitability and liquidity ratios from class exercises (concrete experience), followed by analysing a case study and making recommendations based upon these various ratios.

As stated by Wynn-Williams, Whiting, and Adler (2008), it was believed that business learners in general, and accounting learners in particular, displayed a "converger" learning style. However, more recently, this idea has been challenged because later studies suggest that accounting learners evidence a wider variety of learning styles, with the "assimilator" and "accommodator" styles being often equally present as the "converger" style (Wynn-Williams, Whiting, & Adler, 2008).

Besides Kolb's Learning Style Instrument, other models of learning have been used or referred to recently in accounting education. Between others, it is possible to highlight the Gregorc Learning Styles, the Canfield Learning Styles Inventory, the Myers-Briggs Type Indicator, and the Honey and Mumford's Learning Style Questionnaire.

2.3 Assessment and accounting education

Following Schunk (2014), the methods of assessing learning include: direct observations, written responses, oral responses, ratings by others, and self-reports. According with the same source, self-reports can take several forms: questionnaires, interviews, stimulated recalls (recall of thoughts accompanying one's performance at given times), think-alouds (verbalizing aloud one's thoughts, actions, and feelings while performing a task), and dialogues.

Assessments can also be formative (assessment for learning) or summative (assessment of learning). As various assessment methods can be used to evaluate students' achievements of learning outcomes, these assessment methods may have an impact on the performance of students with particular learning styles (Tan & Laswad, 2015). Therefore, it is important that accounting educators resolve to use a variety of these methods in order for individual learners to have the opportunity to demonstrate their true ability and capability.

3. FACILITATING LEARNING TO THE ACCOUNTING LEARNERS

A class with a large diversity of learning preferences places challenges on the educator. For example, based on Kolb's types of learners, Baker, Simon, and Bazeli (1987) argue that concrete learners value personal experience, on-the-job training, learning from co-workers, the interaction with others, therefore examples of situations that facilitate learning could be talks by experts, student feedback, exercises and simulations. Reflective learners like pictures and demonstrations, prefer passive learning situations, therefore situations that facilitate learning could be lectures, small group discussion, summaries, examinations, and individual conferences with faculty. Abstract learners enjoy building theory using inductive and hypothetical-deductive methods, enjoy impersonal learning environment, therefore situations that facilitate learning could be case studies, readings on theory, and thinking alone. Active learners enjoy a task-oriented course with a great deal of autonomy, concentrate on practitioner roles, apply principles to problems, therefore situations that facilitate learning could be homework, student feedback, projects, and small group discussion.

Nowadays, employers are expecting graduates entering the profession to have the top three skills: analytical/problem solving skills, a level of business awareness or real-life experience and basic accounting skills. However, employers also expect oral communication skills, ethical awareness and professional skills, teamwork, written communication and understanding of the interdisciplinary nature of business.

Moreover, as stated before, usually students do not present the same preferences to the mode of learning. This scenario places an urgent need for change in the teaching methods used by accounting educators, with the aim of leaving the focus on just technical accounting and adopting a holistic way of teaching. In my opinion, for example:

- Different teaching methods between lectures and tutorials can be implemented to teach non-technical skills, values

and attitudes;
- Role play can be used to discuss ethical dilemmas or negotiating skills;
- Case studies can be used for enhancing and understanding the broader business environment and decision making;
- Computerized business simulations, digital video technology, and spreadsheet models can be used to develop decision making skills and introduce situated learning;
- Socratic dialogue can be used to develop critical reasoning;
- Problem based learning ("learning by doing") can be used to enhance critical thinking;
- Field trips, seminars, guest lecturers (with professionals of the area and alumni), and internships can be used to increase business awareness and to have a better idea about "real life";
- Non-traditional tools such as creative writing (fairy tales, fables, poems) can be used to enhance oral and writing communication skills;
- New technologies (such as Kahoot and Nearpod) can be used to engage more learners and make the learning process funnier;
- Accounting educators should discuss with other accounting educators how to implement more effective educating strategies;
- Accounting educators should try to choose appropriate assessment methods in order to promote active learning;
- Accounting educators should give continuous feedback to accounting learners, in order to improve the learning process;
- Accounting educators should discuss with educators from other areas how to achieve synergies between different courses (including interdisciplinary assignments and projects).

CONCLUSIONS

Looking to the required competencies for the professional accountants, mostly in a changing world like ours, and sometimes dealing with very heterogeneous classes (in terms of age, prior knowledge, culture, and motivation), having a good expertise in accounting is not enough to be a good accounting educator. Knowledge about learning theories, learning styles, different kinds of assessment, and different teaching methods and tools, is also fundamental to be an effective accounting educator.

Following Lucas and Milford (2009), two major starting points of teaching and learning in accounting, business and management are: listening to learners and asking learners to reflect on their learning. Therefore, an essential goal of education should be supporting learners in developing their ability to think critically.

In a world where technology is everywhere, accounting educators should also be able to deal with new technologies. However, more than being an end itself, the use of new technologies should be only a mean to achieve a better learning process (Kirkwood, 2014).

Educators in general, and accounting educators in particular, face a large number of challenges. Only a holistic approach can help educators to deal with all those challenges. In this kind of approach, educators should try to help students do be critical, confident and independent, making learning a process of self-improvement that recognizes not only the individual needs of the learner but also the social context of learning and teaching interaction (Patel, 2003).

In summary, even if an educator has a very good academic background, and significant professional experience in the teaching area; even if he uses innovative teaching technologies; if the educator does not listen learners; if the educator does not understand that each individual learner has a different background, cultural experience and way of learning; if the educator does not understand that there is no standardized way to teach, this educator will not succeed. After all, an educator is, at the same time, a learner…

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IMPLEMENTAÇÃO DO CONTROLO ESTATÍSTICO DO PROCESSO NUMA LINHA DE ENGARRAFAMENTO NA INDÚSTRIA VINÍCOLA

IMPLEMENTATION OF STATISTICAL PROCESS CONTROL IN A BOTTLING LINE IN WINERY INDUSTRY

IMPLEMENTACIÓN DEL CONTROL ESTADÍSTICO DEL PROCESO EN UNA LÍNEA DE ENGARRAFAMENTO EN LA INDUSTRIA VINÍCOLA

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RESUMO

Introdução: A grande exigência dos mercados tem conduzido a situações em que os sistemas produtivos são caracterizados pela produção de diversos lotes mas de reduzida dimensão. Este novo paradigma exige que sejam desenvolvidas técnicas adequadas, tanto em termos de planeamento como em termos de Controlo Estatístico do Processo (*SPC*), uma vez que podem existir situações em que não é possível proceder à recolha de dados suficientes para se estimar convenientemente os parâmetros do processo (média e variância).
Objectivos: Implementação do Controlo Estatístico do Processo na indústria vitivinícola para melhorar a qualidade do produto final.
Métodos: Quando nos confrontamos com situações em que não é possível proceder à recolha suficiente de dados, a abordagem sugerida consiste em adotar os desenvolvimentos propostos por Charles Quesenberry. Nestes casos, a estatística da amostra no instante *i* é transformada através das estimativas dos parâmetros do processo recorrendo à informação obtida (dados) até ao instante (*i*-1). O estudo univariado da capacidade do processo é realizada através dos índices de capacidade Q_L e Q_U. São abordadas duas situações de controlo estatístico, uma em que é feito um estudo univariado, com base em cartas *Q*, e outra em que é feito o estudo multivariado, com base nas cartas *MQ*.
Resultados: Este estudo refere-se à implementação do SPC , de uma marca de vinho que possui baixos volumes de produção, no seu processo de engarrafamento, que é considerado que é considerado uma etapa critica uma vez que é necessário ter alguns cuidados como por exemplo o evitar a ocorrência de contaminações microbiológicas ou a oxidação do vinho.
Conclusões: Sempre que não seja possível aplicar cartas de controle tradicionais, a utilização das cartas de controlo Q (análise univariada) e as cartas de controlo MQ (análise multivariada) revela-se a escolha mais adequada, não só para o controlo de um ou mais produto como para vários conjuntos de características da qualidade.

Palavras-chave: SPC (Controlo Estatístico do Processo), Cartas de Controlo, Cartas de Controlo MQ, Short-Runs, Capacidade do Processo

ABSTRACT

Introduction: The great demand of the markets has led to situations in which the production systems are characterized by the production of several batches but of small size. This new paradigm requires that adequate techniques be developed, both in terms of planning and in terms of Statistical Process Control (SPC), since there may be situations where it is not possible to collect enough data to properly estimate the parameters of the process (mean and variance).
Objectives: Implementation of Statistical Process Control techniques in a wine industry in order to improve its final product.
Methods: Whenever there is not enough data to properly estimate the parameters of the process, the suggested approach, is to adopt the developments proposed by Charles Quesenberry. In this case, the statistic of the sample at time *i* is transformed through the estimations of the process parameters using the information obtained (data) until the instant (*i*-1). The univariate study of process capability is performed through the capability indices Q_L and Q_U. Thus, in this paper, two situations of statistical control are addressed, one in which a univariate study is done, based on *Q* charts, and another in which the multivariate study is made, based on the *MQ* charts.
Results: This study comprised the implementation of the SPC) of a wine brand that has low production volumes, in the process of bottling wine, which is considered a critical step since some care is needed, such as avoiding the occurrence of microbiological contaminations or oxidation of the wine.
Conclusions: Whenever it is not possible to apply traditional control charts the use of the control Q charts (univariate analysis) and the control MQ charts (multivariate analysis) are the most appropriate choice not only for the control of one or more products but also for several sets of quality characteristics.

Keywords*:* Statistical Process Control, Control Charts, MQ Control Charts, Short-Runs, Process Capability.

RESUMEN

Introducción: La gran exigencia de los mercados ha conducido a situaciones en que los sistemas productivos se caracterizan por la producción de diversos lotes de reducida dimensión. Este nuevo paradigma exige que se desarrollen técnicas adecuadas tanto en términos de planificación como de control estadístico del proceso (SPC), ya que pueden existir situaciones en las que no es posible proceder a la recogida de datos suficientes para estimar convenientemente los parámetros del proceso (media y varianza).
Objetivos: Aplicación del control estadístico del proceso en la industria vitivinícola para mejorar la calidad del producto final.
Métodos: Cuando nos enfrentamos con situaciones en que no es posible proceder a la recogida suficiente de datos, el enfoque sugerido consiste en adoptar los desarrollos propuestos por Charles Quesenberry. En estos casos, la estadística de la muestra en el instante i se transforma a través de las estimaciones de los parámetros del proceso recurriendo a la información obtenida

(datos) hasta el instante (i-1). El estudio univariado de la capacidad del proceso se realiza a través de los índices de capacidad QL y QU. Se abordan dos situaciones de control estadístico, una en que se realiza un estudio univariado, basado en cartas Q, y otra en que se realiza el estudio multivariado, sobre la base de las cartas MQ.
Resultados: Este estudio se refiere a la implementación del SPC, de una marca de vino que tiene bajos volúmenes de producción, en su proceso de embotellado, que se considera que se considera una etapa crítica, ya que es necesario tener algunos cuidados como por ejemplo evitar que se produzcan contaminaciones microbiológicas o la oxidación del vino.
Conclusiones: Siempre que no sea posible aplicar cartas de control tradicionales, la utilización de las cartas de control Q (análisis univariado) y las cartas de control MQ (análisis multivariado) se revela la elección más adecuada, no sólo para el control de uno o más producto como para varios conjuntos de características de calidad.

Palabras clave: SPC (Control Estadístico del Proceso), Cartas de Control, Cartas de Control MQ, Short-Runs, Capacidad del Proceso

INTRODUCTION

The Statistical Process Control (SPC) has become a crucial tool to ensure the competitive advantage of any company in relation to its competition. The demand of consumers, due to the consistency of quality, entails great efforts at the level of guaranteeing the stability of the processes and of minimizing the variability around the desired values for the quality characteristics. According to Pereira and Requeijo (2012) and Qiu (2014) The major goal of SPC is to monitor sequential processes, to ensure that they operating stably and satisfactorily by constructing a statistical control charts that allow not only reducing the inherent variability of the process, but also estimate the parameters to it and to determine if it is capable of producing according to the specifications defined in the design and development phase.
The univariate control charts were introduced by Shewhart (1931) and have been used in several industrial environments, both for the control of discrete variables and for the control of continuous variables. This type of statistical techniques assumes Normality, Randomness and Independence of data. In situations where there is a need to control various quality characteristics, multivariate control charts are more advantageous since they allow the simultaneous analysis of two or more characteristics in a single chart. As in the univariate study it is necessary to confirm the Normality, Randomness and Independence of the data used. This topic has been developed by several authors, Pignatiello and Runger (1990), Pereira and Requeijo (2012), Montgomery (2012), Wand et al. (2015), between others. However there are situations in which there is no possibility of estimating the process parameters due to insufficient data available. To this end, the developments of Quesenberry (1997) should be used, which transforms a certain statistic of a sample of a certain quality characteristic under study, *X*, in a variable, *Q*, which in turn follows, approximately, the Standard Normal distribution, with mean zero and variance one. For the multivariate situation, these developments were adapted where the statistic *MQ* represents a transformation of the vector of means at a given instant *r.*
The paper is organized as follows. Section 2 presents the authors' proposed methodology. Section 3 provides the background to understand the Statistic Process Control univariate approach, while Section 4 describes the background for the Statistic Process Control multivariate approach. Section 5 includes a case study based on an industry of the wine sector aiming to assess the robustness of the authors´ proposed approach, including a discussion of the results achieved. In Section 6 some concluding remarks are provided.

1. METHODS

When the amount of data concerning the quality characteristics of the study are restricted i.e., when there is not enough information to properly estimate the process parameters, the authors of this paper suggest the methodology depicted in Figure 1.

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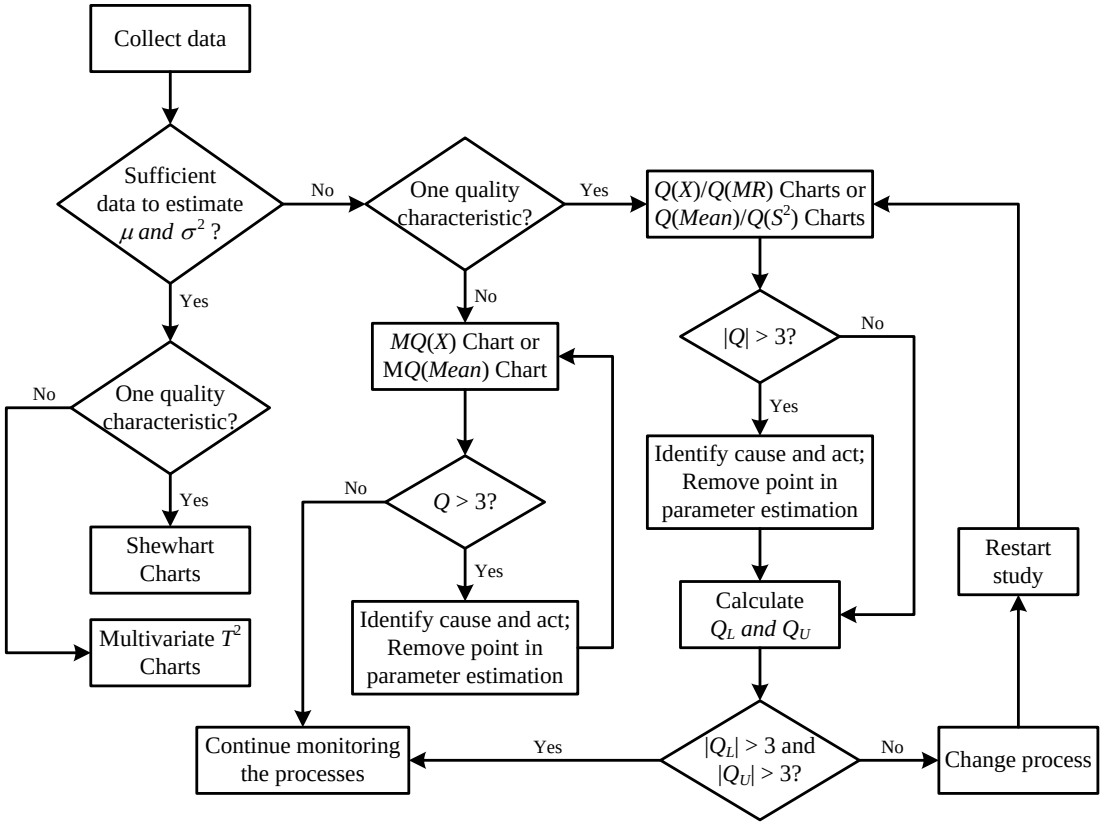

Figure 1. A holistic methodology for implementation of the SPC

2. UNIVARIATED SPC

The implementation of SPC depends on the amount of data available in the control of the various characteristics of the quality under study. Thus, there are two distinct situations, when there are enough data to properly estimate the process parameters (mean and variance) and when there is a limited amount of data which prevents a proper estimation of the processes parameters.

When it is possible to conveniently estimate the process parameters, the SPC is developed in two stages, Phase I and Phase II, using the traditional charts of Shewhart (Phase I) and with dimensionless *Z* and *W* charts (Phase II). It should be noted that the study is only one quality characteristic, it should be applied in the Phase I of SPC the charts of Shewhart. For several characteristics/products to be controlled, it is suggested to implement the *Z* and *W* charts which include all the characteristics/products in the same chart.

2.1. Sufficient Data

For the correct implementation of the Shewhart charts (Traditional Control Charts), in addition to Normality, Independence and Randomness, it is necessary to ensure that the sampling frequency, or individual observations, is made within a period of time that is significant enough to ensure that the data collected reflect the behaviour of the process. Authors as Quesenberry (1997), Pyzdek (1999), Ryan (2000), Pereira and Requeijo (2012) and Montgomery (2012), between others, consider that the procedure for the construction of control charts is based on two distinct phases. A first phase (Phase I) in which the stability of the process is verified in order to estimate its parameters and to study its capability. And a second phase (Phase II) which, after being confirmed in Phase I, the process is controlled and which has ability to produce according to the technical specification required, then proceeds to the monitoring thereof.

2.1.1. Phase I

At this stage the stability of the process is ascertained, as such the upper and lower control limits are calculated (*UCL* and *LCL*, respectively), which in turn are at a distance from the center line (*CL*) of ± 3 standard deviation of the sample statistical distribution to be controlled, which corresponds to a level of significance of 0,27%. After checking that the process is under control, that is, when all samples corresponding to special causes have been removed and no non-random patterns are evident, the parameters must be estimated. The various estimates, calculated from the data collected, are presented in Table 1.

Table 1 - Control Limits for Shewhart charts of Phase I and process parameters estimators.

Carta	*LCL*	*CL*	*UCL*	$\hat{\mu}$	$\hat{\sigma}$
X	$\overline{X}-3\left(\overline{MR}/d_2\right)$	$\overline{X}$	$\overline{X}+3\left(\overline{MR}/d_2\right)$	$\overline{X}$	
$\overline{X}$	$\overline{\overline{X}}-A_2\overline{R}$ ou $\overline{\overline{X}}-A_3\overline{S}$	$\overline{\overline{X}}$	$\overline{\overline{X}}+A_2\overline{R}$ ou $\overline{\overline{X}}+A_3\overline{S}$	$\overline{\overline{X}}$	
R	$D_3\overline{R}$	$\overline{R}$	$D_4\overline{R}$		$\overline{R}/d_2$
S	$B_3\overline{S}$	$\overline{S}$	$B_4\overline{S}$		$\overline{S}/c_4$
MR	$D_3\overline{MR}$	$\overline{MR}$	$D_4\overline{MR}$		$\overline{MR}/d_2$

In the equations in Table 1 it is considered:

- n – sample size;
- μ – estimated process mean;
- σ – estimated process standard deviation;
- X – individual observation;
- R – sample range;
- S – sample standard deviation;
- MR – moving range;
- $\overline{X}$ – sample mean;
- $\overline{\overline{X}}$ – average of the samples means;
- $\overline{R}$ – average of the range samples;
- $\overline{S}$ – average of the samples standard deviations;
- $\overline{MR}$ – average of the moving ranges;
- $A_2, A_3, B_3, B_4, D_3, D_4, d_2, c_4$ – constants that depend on the sample size n.

After verifying that the process is under statistical control and to make the estimation of their parameters, it is possible to analyse the process capability with regard to its technical specification, in which *LSL* is the lower specification limit and *USL* is the upper specification limit. Usually are used the indexes, C_p and C_{pk}, for Normally distributed data, which in turn can be obtained through the following equations:

$$C_p = \frac{USL - LSL}{6\sigma} \quad (1)$$

$$C_{pk} = min\left(\left(C_{pk}\right)_L, \left(C_{pk}\right)_U\right) \quad (2)$$

$$\left(C_{pk}\right)_L = \frac{\mu - LSL}{3\sigma} \quad (3)$$

$$\left(C_{pk}\right)_U = \frac{USL - \mu}{3\sigma} \quad (4)$$

Traditionally a process is considered capable if C_p and C_{pk} are simultaneously greater than 1.33 if the technical specification is bilateral, or 1.25 if one is faced with unilateral technical specifications. In order to confirm the assumptions mentioned above, it is suggested to use the Test of Kolmogorov-Smirnov to verify the Normality of the process and the implementation of the Auto Correlation Functions (*ACF*) and Partial Auto Correlation Functions (*PACF*), to verify the independence.

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2.1.2. Phase II

Once the stability of the process has been verified, the parameters of the process have been estimated and the capability study has been carried out, there are conditions to proceed to Phase II of the *SPC* that is related to process monitoring.

When there are several characteristics/products under control, it is suggested the use of *Z* and *W* charts. These charts are constructed based on the transformation of a variable *X* (or $\overline{X}$) and *S* (or *R*, or *MR*), thus allowing different characteristics of various products to be represented on the same chart. In Table 2, for a instant *i* and product *j*, we present the equation used in the calculation of the statistics of the charts *Z* and *W*.

Table 2 – Statistics of the *Z* and *W* charts and their control limits and centreline.

$Z_{\overline{X}}$ and W_S Chart	$Z_{\overline{X}}$ and W_R Chart	Z_X and W_{MR} Chart
$(Z_i)_j = \left(\frac{\overline{X}_i - \mu}{\sigma_{\overline{x}}}\right)_j$	$(Z_i)_j = \left(\frac{\overline{X}_i - \mu}{\sigma_{\overline{x}}}\right)_j$	$(Z_i)_j = \left(\frac{X_i - \mu}{\sigma}\right)_j$
$(W_i)_j = \left(\frac{S_i}{\overline{S}}\right)_j$	$(W_i)_j = \left(\frac{R_i}{\overline{R}}\right)_j$	$(W_i)_j = \left(\frac{MR_i}{\overline{MR}}\right)_j$
$LSC_Z = 3$ $LSC_W = B_4$	$LSC_Z = 3$ $LSC_W = D_4$	$LSC_Z = 3$ $LSC_W = D_4$
$LC_Z = 0$ $LC_W = 1$	$LC_Z = 0$ $LC_W = 1$	$LC_Z = 0$ $LC_W = 1$
$LIC_Z = -3$ $LIC_W = B_3$	$LIC_Z = -3$ $LIC_W = D_3$	$LIC_Z = -3$ $LIC_W = D_3$

In the equations in Table 2 it is considered the following notation:

- $(n_i)_j$ - sample size *i* for product *j*;
- $(R_i)_j$ - sample range *i* for product *j*;
- $(S_i)_j$ - sample standard deviation *i* for product *j*;
- $(MR_i)_j$ - moving range *i* for product *j*;
- $(\overline{X}_i)_j$ - sample mean *i* for product *j*;
- $(\overline{S})_j$ - average of the samples standard deviations for product *j*;
- $(\overline{R})_j$ - average of the range samples for product *j*;
- $(\mu)_j$ - process mean relative to characteristic *X* for product *j*;
- $(\sigma)_j$ - process standard deviation relative to characteristic *X* for product *j*;
- $(\sigma_{\overline{x}})_j$ - standard deviation of the sample means distribution for the product *j.*

With this type of charts, it is possible to analyse the process capability in real time through the indices Z_L and Z_U, developed by Pereira and Requeijo (2012). Table 3 presents the equations that allow to obtain the respective estimators and indices at each moment *r*.

Table 2 - Capacity index and parameters estimators for the charts Z

Index/Estimator	Equation
$\left(\left(\hat{Z}_U\right)_r\right)_j$	$\left(\frac{USL-\hat{\mu}_r}{k\,\hat{\sigma}_r}\right)_j$
$\left(\left(\hat{Z}_L\right)_r\right)_j$	$\left(\frac{LSL-\hat{\mu}_r}{k\,\hat{\sigma}_r}\right)_j$
$\hat{\mu}_r=\overline{\overline{X}}_r$	$\overline{\overline{X}}_r=\frac{1}{r}\left((r-1)\overline{\overline{X}}_{r-1}+\overline{X}_r\right) \quad , \quad r=2,3,\ldots$
$\hat{\mu}_r=\overline{X}_r$	$\overline{X}_r=\frac{1}{r}\left((r-1)\overline{X}_{r-1}+X_r\right) \quad , \quad r=2,3,\ldots$
$\hat{\sigma}_r=\frac{\overline{S}_r}{c_4}$	$\overline{S}_r=\frac{1}{r}\left((r-1)\overline{S}_{r-1}+S_r\right) \quad , \quad r=2,3,\ldots$
$\hat{\sigma}_r=\frac{\overline{R}_r}{d_2}$	$\overline{R}_r=\frac{1}{r}\left((r-1)\overline{R}_{r-1}+R_r\right) \quad , \quad r=2,3,\ldots$
$\hat{\sigma}_r=\frac{\overline{MR}_r}{d_2}$	$\overline{MR}_r=\frac{1}{r}\left((r-1)\overline{MR}_{r-1}+MR_r\right) \quad , \quad r=2,3,\ldots$

To be capable, the index Z_U must be greater than 3 and the index Z_L must be lower than -3. The value of k is usually equal to 1.33 for bilateral specifications and 1.25 for unilateral specifications.

2.2. Restricted Data

In situations where there are insufficient data to estimate the parameters of a particular process, should be used the approach proposed by Quesenberry (1997), which are based on the construction of the *Q* charts. As in the situation where there is sufficient data, the data collected must follow an approximately Normal distribution and must be independent.

In the case of data being individual observations, one should use the *Q*(*X*) chart in the control of the process mean and the *Q*(*MR*) chart in controlling the process dispersion. To the *Q*(*X*) chart, the value of individual observation *X*, in a certain moment *r* (X_r), is transformed into statistics $Q_r(X_r)$ given by the following equation:

$$Q_r\left(X_r\right)=\Phi^{-1}\left(G_{r-2}\left(\sqrt{\frac{r-1}{r}}\left(\frac{X_r-\overline{X}_{r-1}}{S_{r-1}}\right)\right)\right) \quad , \quad r=3,4,\ldots \tag{5}$$

Regarding the *Q*(*MR*) chart the statistic that is represented graphically, in order to control the dispersion for a certain instant *r*, is given by the following equation:

$$Q_r\left(MR_r\right)=\Phi^{-1}\left(F_{1,v}\left(\frac{v\left(MR\right)_r^2}{\left(MR\right)_2^2+\left(MR\right)_4^2+\cdots+\left(MR\right)_{r-2}^2}\right)\right) \quad , \quad r=4,6,\ldots \tag{6}$$

In equations (5) and (6) the following notation was used:

- X_r - observation in instant *r*;
- $\overline{X}_{r-1}$ - average of the $(r-1)$ observations;
- S_{r-1} - sample standard deviation constituted by $(r-1)$ observations;

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MR_r - moving range determined in the observation *r*;

$\Phi^{-1}(\square)$ - inverse of the Normal Distribution Function;

$G_\nu(\square)$ - Distribution Function t-student, with ν freedom degrees;

$F_{\nu_1,\nu_2}(\square)$ - Fisher Distribution Function, with ν_1 and ν_2 freedom degrees.

Since the variables *Q(X)* and *Q(MR)* are Normally distributed according to the Standard Normal distribution, the control limits of these charts are given by,

$$\begin{aligned} UCL_{Q(X)} &= 3 \qquad & UCL_{Q(MR)} &= 3 \\ CL_{Q(X)} &= 0 \quad \text{and} \quad & CL_{Q(MR)} &= 0 \\ LCL_{Q(X)} &= -3 \qquad & LCL_{Q(MR)} &= -3 \end{aligned} \tag{7}$$

As regards the situation where the data collected are samples, should be made to the construction of the $Q(\overline{X})$ and $Q(S^2)$ charts. The statistic represented graphically in the $Q(\overline{X})$ chart for the sample *i,* is given by the following equation:

$$Q_i(\overline{X}_i) = \Phi^{-1}\left(G_{\nu_1+\ldots+\nu_i}(\omega_i)\right) \;,\; i=2,3,\ldots \;,\; \nu_i = n_i - 1 \tag{8}$$

where,

$$\omega_i = \sqrt{\frac{n_i(n_1+\ldots+n_{i-1})}{n_1+\ldots+n_i}}\left(\frac{\overline{X}_i - \overline{\overline{X}}_{i-1}}{s_{p,i-1}}\right) \quad , \quad i=2,3,\ldots \tag{9}$$

To control the dispersion, it should be represented in the $Q(S^2)$ chart, for a sample *i*, the statistic given by the following equation:

$$Q_i(S_i^2) = \Phi^{-1}\left(F_{\nu_i,\nu_1+\ldots+\nu_{i-1}}(\theta_i)\right) \;,\; i=2,3,\cdots \;,\; \nu_i = n_i - 1 \tag{10}$$

where,

$$\theta_i = \frac{S_i^2}{S_{p,i-1}^2} \quad , \quad i=2,3,\ldots \tag{11}$$

$$S_{p,i}^2 = \frac{\nu_1 S_1^2+\ldots+\nu_i S_i^2}{\nu_1+\ldots+\nu_i} = \frac{\sum_{j=1}^{i}\nu_j S_j^2}{\sum_{j=1}^{i}\nu_j} \quad , \quad \nu_i = n_i - 1 \tag{12}$$

As in the situation where the data are individual observations, the variables $Q(\overline{X})$ and $Q(S^2)$ are Normally distributed according to a standard Normal distribution, so the control limits of these charts will be given by,

$$\begin{aligned} UCL_{Q(\overline{x})} &= 3 \qquad & UCL_{Q(s^2)} &= 3 \\ CL_{Q(\overline{x})} &= 0 \quad \text{and} \quad & CL_{Q(s^2)} &= 0 \\ LCL_{Q(\overline{x})} &= -3 \qquad & LCL_{Q(s^2)} &= -3 \end{aligned} \tag{13}$$

Regarding the process capability, it is monitored in real time as the data are collected based on the indexes Q_L and Q_U. Table 4 shows the equations needed to calculate these statistics.

Table 3 – Capability index for charts *Q*.

Carta	Q_L	Q_U	$\hat{\mu}_r$	$\hat{\sigma}_r$
$Q(X)$	$\left(\hat{Q}_L\right)_r = \frac{LSL - \hat{\mu}_r}{k\,\hat{\sigma}_r}$	$\left(\hat{Q}_U\right)_r = \frac{USL - \hat{\mu}_r}{k\,\hat{\sigma}_r}$	$\bar{\bar{X}}_r$	$\frac{S_r}{c_4}$
$Q(\bar{X})$	$\left(\hat{Q}_L\right)_r = \frac{LSL - \hat{\mu}_r}{k\,\hat{\sigma}_r}$	$\left(\hat{Q}_U\right)_r = \frac{USL - \hat{\mu}_r}{k\,\hat{\sigma}_r}$	$\bar{\bar{X}}_r$	$\frac{S_{p,r}}{c_4}$

As in the case of the *Z* and *W* charts, for the process to be capable it is necessary that the index Q_L is lesser than -3 and the index Q_U is greater than 3. The value of *k* is usually equal to 1.33 for bilateral specifications and 1.25 for unilateral specifications.

3. MULTIVARIATE SPC

When it is desired to control more than one quality characteristic simultaneously, multivariate statistical control appears as the most adequate alternative, since it allows controlling simultaneously the two or more variables under study, as well as the correlation between them, being only necessary the construction of a control chart. In addition, joint control of variables may allow the identification of potential alarming situations, which in turn could be overlooked in the univariate charts. As univariate SPC, there are two distinct situations, when there is sufficient data to adequately estimate the process parameters (mean vector and the covariance matrix) and when the amount of data is insufficient for adequate estimation of the parameters.

3.1. Sufficient Data

When there are sufficient data to adequately estimate the mean vector of the process and the matrix of covariance, multivariate *SPC* is based, like the univariate SPC, in two distinct phases (Phase I and Phase II). In Phase I the stability of the process is verified and the process capability is analysed. In Phase II, the process is monitored. The assumptions to be verified are identical to those of the univariate study. The T^2 chart is the statistical technique of excellence for the multivariate control of the mean vector of the process. Table 5 shows the types of multivariate control charts and statistics that are plotted.

Table 4 – Multivariate control charts and their statistics.

Nature of the Data	Chart	Statistics
Samples	T^2 (Phase I)	$\left(T^2\right)_k = n\left(\bar{\mathbf{X}}_k - \bar{\bar{\mathbf{X}}}\right)' \mathbf{S}^{-1}\left(\bar{\mathbf{X}}_k - \bar{\bar{\mathbf{X}}}\right)$
	T^2 (Phase II)	
	χ^2 (Phase II)	$\left(\chi^2\right)_k = n\left(\bar{\mathbf{X}}_k - \boldsymbol{\mu}\right)' \boldsymbol{\Sigma}^{-1}\left(\bar{\mathbf{X}}_k - \boldsymbol{\mu}\right)$
Individual Observations	T^2 (Phase I)	$\left(T^2\right)_k = \left(\mathbf{X}_k - \bar{\mathbf{X}}\right)' \mathbf{S}^{-1}\left(\mathbf{X}_k - \bar{\mathbf{X}}\right)$
	T^2 (Phase II)	
	χ^2 (Phase II)	$\left(\chi^2\right)_k = \left(\mathbf{X}_k - \boldsymbol{\mu}\right)' \boldsymbol{\Sigma}^{-1}\left(\mathbf{X}_k - \boldsymbol{\mu}\right)$

Table 6 shows the control limits for each type of multivariate control charts.

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Table 5 - Control Limits for Multivariate Charts

Nature of the Data	Chart	*UCL*	*LCL*
Samples	T^2 (Phase *I*)	$\frac{p\,(m-1)\,(n-1)}{mn-m-p+1}\cdot F_{\alpha;p,mn-m-p+1}$	*0*
	T^2 (Phase II)	$\frac{p\,(m+1)\,(n-1)}{mn-m-p+1}\cdot F_{\alpha;p,mn-m-p+1}$	
	χ^2 (Phase II)	$\chi^2_{\alpha;p}$	
Individual Observations	T^2 (Phase I)	$\frac{(m-1)^2}{m}\beta_{\alpha;p/2,(m-p-1)/2}$	
	T^2 (Phase II)	$\frac{p(m+1)\,(m-1)}{m\,(m-p)}\cdot F_{\alpha;p,m-p}$	
	χ^2 (Phase II)	$\chi^2_{\alpha;p}$	

In the equations in Table 5 and Table 6 the following notation was used:

- n – sample size;
- m – number of samples;
- p – number of quality characteristics;
- $\mathbf{X}_k$ – individual observations vector at instant k;
- $\bar{\mathbf{X}}_k$ – mean vector of sample k;
- $\bar{\bar{\mathbf{X}}}$ – mean vector of samples average;
- $\mathbf{S}$ – sample covariances matrix;
- $\boldsymbol{\mu}$ – process mean vector;
- $\boldsymbol{\Sigma}$ – process covariances matrix;
- $\beta_{\alpha;a,b}$ – right percentile, for a probability α, of a Beta distribution with parameters a and b;
- $F_{\alpha;\nu_1,\nu_2}$ – right percentile, for a probability α, of a Fisher distribution with ν_1 and ν_2 freedom degrees in numerator and denominator respectively.
- $\chi^2_{\alpha;p}$ – right percentile, for a probability α, of a Chi-Square distribution with ν freedom degrees.

In this type of control charts, after identifying and removing all special causes of variation, the process capability is studied. In the scope of the multivariate capability study, it is suggested to use of C_{pM} index, which evaluates the potential capability of the process, very similar to the C_p index of the univariate study, the index *PV* which compares the location of the process mean vector with the target vector of the process and the index *LI* which assesses whether or not the modified region of the process is contained in the region defined by the technical specification. In the case of characteristics with unilateral and bilateral technical specification, refers developments by Jalili *et al*. (2012).

3.2. Restricted Data

Similar to what happens for the univariate study, there are multivariate statistical control techniques suitable for situations where there is insufficient data for the convenient estimation of the mean vector and the covariance matrix of the process. Thus, on the basis of developments in Quesenberry (1997), can be built the *MQ(X)* or $MQ\left(\bar{X}\right)$ chart.
In case the data collected are individual observations, the statistic that is represented in the chart *MQ(X)* is given by the following equation:

$$Q_r\left(\mathbf{X}_r\right)=\Phi^{-1}\left(F_{p,r-1-p}\left(A_r\right)\right) \quad , \quad r=p+2,\ p+3,\ \ldots \tag{14}$$

where,

$$A_r = \left(\frac{(r-1)\ (r-1-p)}{rp\ (r-2)} \right) \left(\mathbf{X}_r - \bar{\mathbf{X}}_{r-1} \right)' \mathbf{S}_{r-1}^{-1} \left(\mathbf{X}_r - \bar{\mathbf{X}}_{r-1} \right) \tag{15}$$

In the situation where the data collected are samples, the chart should be $MQ(\bar{X})$, where the statistic to be represented in the chart is given by the following equation:

$$Q_r(\bar{\mathbf{X}}_r) = \Phi^{-1}\left(F_{p,N_r-r-p+1}(A_r) \right) \quad , \quad r = 2,\ 3,\ \ldots \tag{16}$$

where,

$$A_r = \left(\frac{n_r N_{r-1} (N_r - r + 1 - p)}{N_r p\ (N_r - r)} \right) \left(\bar{\mathbf{X}}_r - \bar{\bar{\mathbf{X}}}_{r-1} \right)' \mathbf{S}_{pool,r}^{-1} \left(\bar{\mathbf{X}}_r - \bar{\bar{\mathbf{X}}}_{r-1} \right) \tag{17}$$

$$N_r = n_1 + \cdots + n_r \tag{18}$$

$$\mathbf{S}_{pool,r} = \frac{1}{N_r - 1} \sum_{i=1}^{r} (n_i - 1)\ \mathbf{S}_i = \frac{1}{N_r - 1} \left((N_{r-1} - r + 1)\ \mathbf{S}_{pool,r-1} + (n_r - 1)\ \mathbf{S}_r \right) \tag{19}$$

$$\mathbf{S}_{pool,0} = \mathbf{0} \tag{20}$$

The control limits and the center line, for this type of charts, are given by:

$$\begin{aligned} &UCL_{MQ(x)} = 3 && UCL_{MQ(\bar{x})} = 3 \\ &CL_{MQ(x)} = 0 \quad \text{and} && CL_{MQ(\bar{x})} = 0 \\ &LCL_{MQ(x)} = -3 && LCL_{MQ(\bar{x})} = -3 \end{aligned} \tag{21}$$

4. CASE STUDY

The case study was carried out in a unit of a leading wine company in the Portuguese market. The company has implemented a quality management system in accordance with the requirements of ISO 9001.

The case study comprised the implementation of the SPC for various products (wine brands) in the process of bottling wine which is considered a critical step since some care is needed, such as avoiding the occurrence of microbiological contaminations or oxidation of the wine.

In general, the bottling lines are divided into cells, there being operators responsible for each of these cells, which in turn may consist of more than one set of machines.

Based on the methodology proposed in Figure 1, it is possible to identify the statistical techniques to apply when there is sufficient data for the convenient estimation of the process parameters (mean and variance) as well as when the data is restricted and as such estimation cannot be performed conveniently.

For the case study presented, two quality characteristics (Filling Volume and Torque applied in the capsule) of a product of the premium range designated "CA" with a very restricted number of units produced were selected, reason why, according to the methodology presented in Figure 1, statistical techniques were applied for this situation, i.e., the Q charts (univariate study) and the MQ charts (multivariate study).

This study was based on the collection of samples with dimension 5 of a wine product that has low production volumes. The key quality characteristics analysed were the filling volume and the torque required to break the sealing capsule.

To this product were collected 15 samples of each of the characteristics under consideration. In this paper an example is presented where the univariate and multivariate analysis was carried out, through the application of the charts.

The procedure used to collect the data concerned with the control of volume consisted of weighing 5 properly identified empty bottles which, after passing through the filling line, are collected and reweighed in order to calculate the net mass value and consequently the volume of filling. In relation to the torque value, adequate equipment was used to measure the torque. The sampling frequency is hourly, and the measuring equipment used is calibrated.

The "filling volume" quality characteristic is measured in "l" (liter) and the limits of the technical specification is equal to 0,750 ± 0,10; the "torque" quality characteristic is measured in "in.lbs" and its technical specification is equal to 15 ± 7.

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4.1. Univariate Analysis

This section includes the SPC study considering an univariate approach based on the problem mentioned above, where two characteristics are analysed.

4.1.1. Filling Volume

In order to control the mean process, 15 samples of size n = 5 were collected for the filling volume of the product "CA" and the $Q(\bar{X})$ chart was constructed, as well as the $Q(S^2)$ chart, which are respectively depicted in Figure 2 and Figure 3.
The statistics $Q(\bar{X})$ and $Q(S^2)$ were determined respectively by equations 8 and 10, based on the means and variances of the 15 samples collected from the production referring to the quality characteristic of "filling volume".
The capacity indexes Q_L and Q_U, represented in the chart $Q(\bar{X})$ of Figure 2 are determined using the equations in Table 4.
Regarding the $Q(\bar{X})$ chart no special causes of variation were detected, but sample 15 is a point that should merit some attention as it is quite close to the lower control limit. In terms of capability, the process has capability, but is not centred since the indexes Q_L e Q_U are not approximately equal in magnitude. In $Q(S^2)$ chart no special causes of variation were detected either, only in the sample 13 an increase in the dispersion of the process occurred, a situation related to a problem in the regulation of the level of filling.

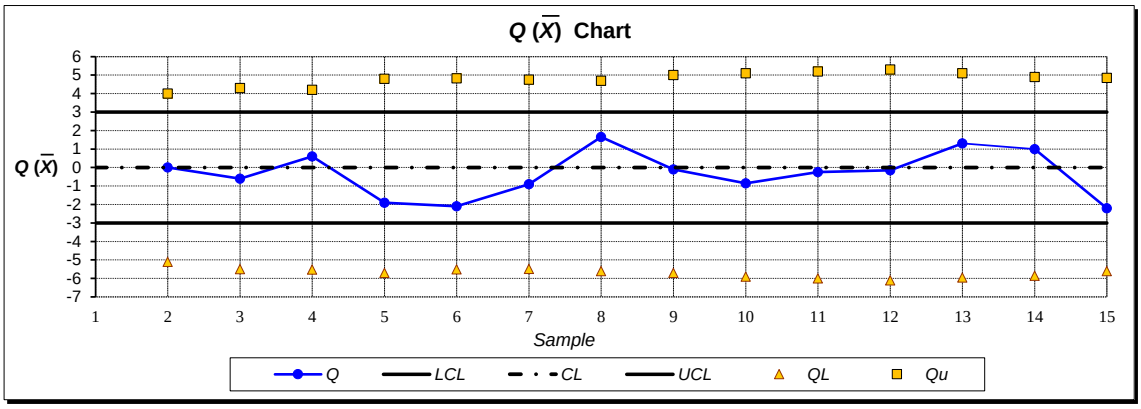

Figure 2. $Q(\bar{X})$ Chart to monitor the filling volume's mean of the product "CA"

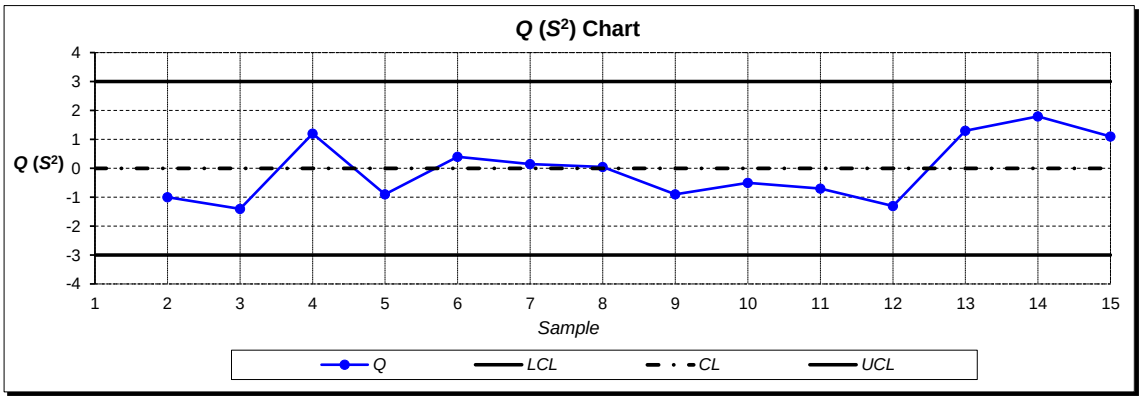

Figure 3. $Q(S^2)$ Chart to monitor the dispersion of the filling volume of product "CA"

4.1.2. Torque Applied in the Capsule

The other characteristic analysed was the torque in the sealing capsule, where 15 samples of size 5 were also collected. Figure 4 and Figure 5 depict, respectively, the $Q(\bar{X})$ chart and the $Q(S^2)$ chart corresponding to this characteristic.
The statistics $Q(\bar{X})$ and $Q(S^2)$ were determined respectively by equations 8 and 10, based on the means and the variances of the 15 samples collected from the production referring to the quality characteristic "torque".
The capacity indexes Q_L and Q_U, represented in the chart $Q(\bar{X})$ of Figure 4 are determined using the equations in Table 4.

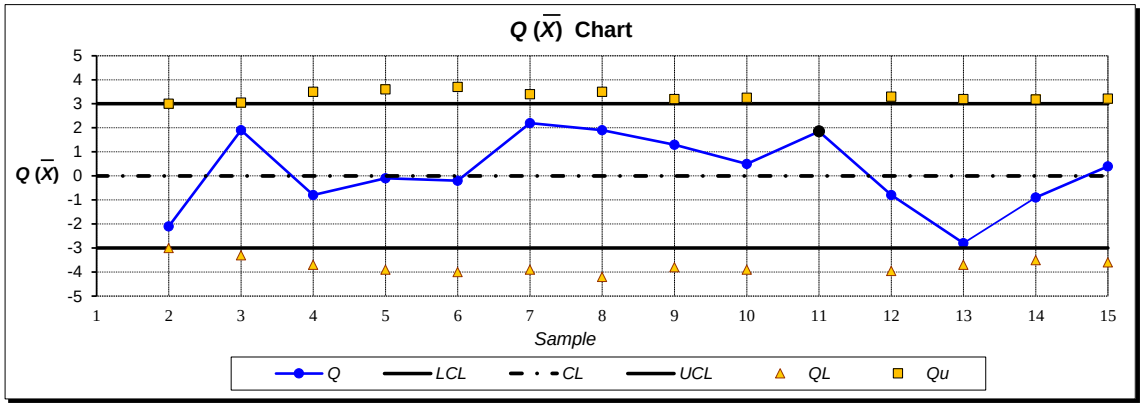

Figure 4. $Q\left(\overline{X}\right)$ Chart to monitor the torque's mean for product "CA"

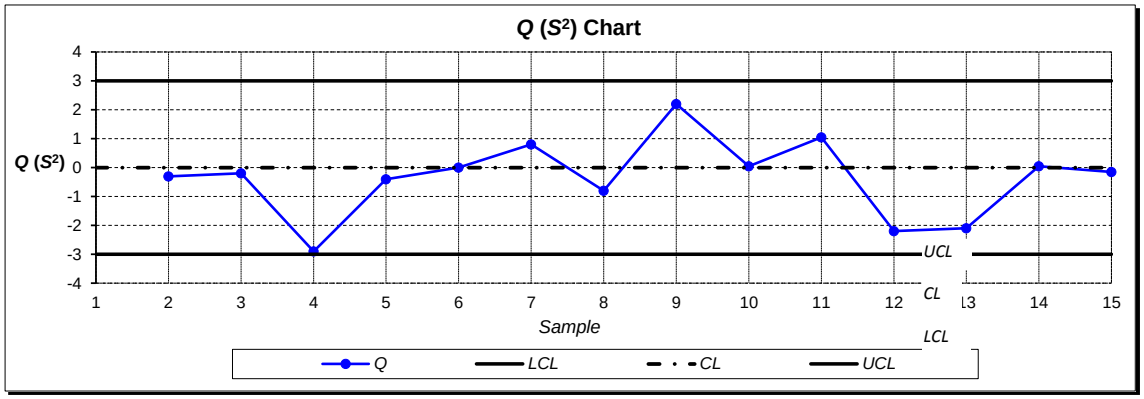

Figure 5. $Q\left(S^2\right)$ Chart to monitor the dispersion of the torque on the closing capsule of product "CA"

In $Q\left(\overline{X}\right)$ chart of this characteristic it is possible to observe the presence of a special cause of variation associated to a non-random pattern (sample 7 to sample 11), which according to ISO 7870-2: 2013 corresponds to rule 6 (four of five consecutive points in the zone B or A or beyond this zone on the same side of the centre line). As such, this sample was duly analysed in order to ascertain the root cause of the problem in the productive process and corrective actions were implemented. In addition to sample 11, there are no more special causes, however sample 13 should merit some attention since the value of the statistic is very close to the lower control limit. In terms of capability, the process is capable but not centred for the same reason already observed for the characteristic filling volume.
Regarding $Q\left(S^2\right)$ chart no special causes of variation were found, however, sample 4 is a point that should merit some attention as it is very close to the lower control limit.

4.2. Multivariate Analysis

When more than one quality feature is controlled simultaneously using the same samples, it is possible to perform the univariate study for each of the quality characteristics, although the multivariate study has advantages. These advantages are revealed on the one hand by the smaller number of documents analysed (increased with the increase in the number of characteristics under study) but mainly for the possibility of controlling not only the values of the characteristics under study but also the correlation between them. The multivariate charts detect special causes of variation when the correlation between the variables is drastically altered, besides obviously a significant change in the value of the characteristic (s) under study. A common example in which the application of multivariate charts is clearly advantageous is the simultaneous control of the thickness and weight of a given piece; in this case the correlation between the weight and the thickness of the piece is positive; if the thickness increases the weight is expected to increase; if this does not happen and this situation is not detected using an univariate chart of weight and thickness, it is probable that the multivariate chart detects this situation due to the change in the correlation between the two quality characteristics that will leave at that moment of being positive and started to be negative. Thus, we chose to perform the multivariate study and compare it with the univariate study presented in section 5.1.

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Then, after the univariate study was done, a multivariate study was carried out through the construction of the $MQ(\bar{X})$ chart, which is shown in Figure 6.
The statistics $MQ(\bar{X})$ was determined by the equation 16, based on the mean vectors and covariance matrices of the 15 samples collected from the production concerned with the quality characteristics "filling volume" and "torque".

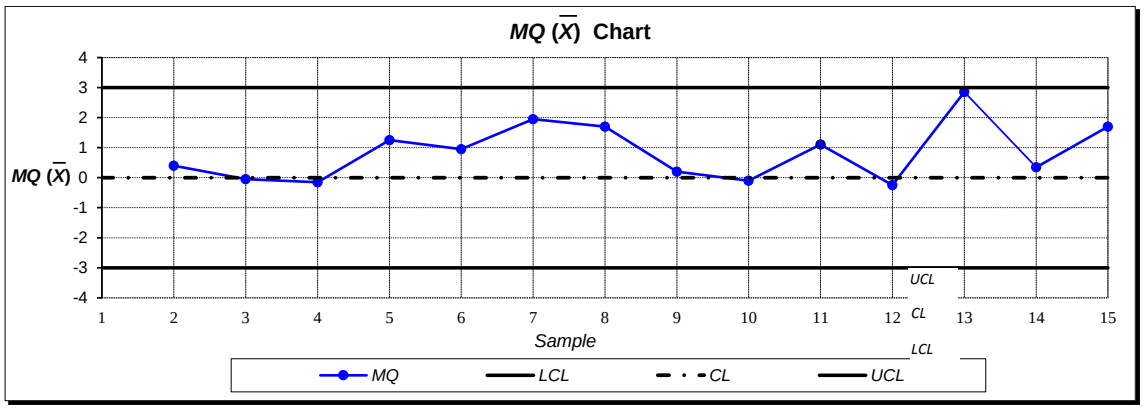

Figura 6. Multivariate $MQ(\bar{X})$ chart for control of the mean vector of the characteristics of the filling volume and product torque "CA".

Through the analysis of the $MQ(\bar{X})$ chart it is possible to verify a special cause of variation (sample 5 to sample 8) referring to a non-random pattern (rule 6). This same non-random pattern was also detected in the $Q(\bar{X})$ chart for the torque characteristic.
The multivariate $MQ(\bar{X})$ chart reveals a greater sensitivity than the chart $Q(\bar{X})$ since this special cause is detected in sample 8 unlike the univariate chart where it was only detected in sample 11.
Another sample that stands out, although not being a special cause of variation, is sample 13 (value of the statistic very close to the control limit) that reflects the situation verified in the univariate chart of the torque.

CONCLUSIONS

The purpose of this study was the implementation of Statistical Process Control techniques in a wine industry in order to improve its final product. For this study, two quality characteristics, the filling volume and the torque required to open the seal cap, were considered.
However, as the case study was applied to products with low production volumes, since bottling is done in small batches, the use of traditional techniques becomes impractical due to the reduced number of data available for parameter estimation which would lead to erroneous conclusions.
Considering, the methodology proposed with the use of the control Q charts (univariate analysis) and the control MQ charts (multivariate analysis) proves to be the most appropriate choice not only for the control of one or more products but also for several sets of quality characteristics.
Furthermore, the methodology followed has several advantages over traditional approaches, as follows:

1) The *Q* charts enable the statistical control of all quality products/characteristics in the same chart, even when there is insufficient data to adequately estimate process parameters (mean and variance);
2) The *MQ* charts allow the simultaneous statistical control of several quality characteristics of several products in the same chart, even when there are not sufficient data to estimate the process parameters (process mean vector and process covariance matrix);
3) Allows to study together different characteristics;
4) Drastically reduces the time for analysis;
5) The introduction in the univariate study ($Q(X)$ or $Q(\bar{X})$ charts) the capability indexes Q_L and Q_U, allows the monitoring of the process capability, proving to be an important added value;
6) The use of capability indexes Q_L and Q_U, which allow studying the process capability in real time, has reduced the probability of producing nonconforming units, i.e., product that does not meet the technical specification.

One of the major drawbacks of *Q* control charts is the difficulty in analysing the existence of non-random patterns, increasing the complexity of this analysis with the number of products/characteristics to control.
Another disadvantage of *Q* and *MQ* charts, in particular the latter, is the poor sensitivity in detecting special causes of variation, specifically at the beginning of the study. Although the lack of sensitivity in detecting non-random patterns is a limitation of the

Q and *MQ* charts, its use nevertheless proves to be of great importance and utility, since traditional univariate and multivariate approaches are not amenable of implementation when there is a restricted number of data. One way to increase the sensitivity of these cards is based on the use of charts with memory, such as the Cumulative Sums charts (*CUSUMQ* and *MCUSUMQ*) and charts of Exponentially Weighted Moving Average (*EWMAQ* and *MEWMAQ*), as referred in Pereira and Requeijo (2012).

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EFEITO DA ADIÇÃO DE CULTURAS DE ARRANQUE NAS PROPRIEDADES FÍSICO-QUÍMICAS E SENSORIAIS DE "ALHEIRA DE VITELA"

EFFECT OF ADDITION OF A STARTER CULTURES ON PHYSICOCHEMICAL AND SENSORY PROPERTIES OF "ALHEIRA", A SMOKED SAUSAGE-LIKE PRODUCT

EFECTO DE LA ADICIÓN DE CULTIVOS INICIADORES SOBRE LAS PROPIEDADES FISICOQUÍMICAS Y SENSORIALES DE "ALHEIRA", UN EMBUTIDO AHUMADO

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RESUMO

Introdução: A alheira é um produto fumado tradicional português que pode ser produzido com diferentes tipos de carne sendo o pão um ingrediente fundamental. A bioconservação de alimentos pela adição de bactérias do ácido láctico (BAL) e das suas bacteriocinas tem ganho especial destaque como forma de controlar naturalmente o crescimento de microrganismos patogénicos e de degradação presentes nos alimentos.
Objectivos: Investigar o efeito de uma cultura de arranque de *Lactobacillus plantarum* ST153Ch fresca e liofilizada nas características físico-químicas e sensoriais de alheira de vitela.
Métodos: As amostras foram produzidas a nível industrial. As amostragens para todos os procedimentos analíticos foram efetuadas aos dias 0, 15, 30, 45, 60, 75, 90 de armazenamento. As características físico-químicas (humidade, pH, atividade de água (a_w), dureza, adesividade, cor (CIE L*, a*, b*) e a análise sensorial realizada à aparência visual, odor, textura e sabor (11 atributos), por um painel de 9 provadores, foram avaliadas ao longo do armazenamento em atmosfera modificada a 4 °C.
Resultados: Foram observadas diferenças significativas (p<0,05) entre todas as amostras no teor de humidade, pH, a_w, dureza, adesividade e cor ao longo do armazenamento.
Conclusões: O painel sensorial não detetou diferenças significativas nas amostras de alheira inoculadas em relação ao controlo até aos 75 dias de armazenamento o que possibilita a aplicação da cultura de *L. plantarum* ST153Ch pelo menos durante esse período.

Palavras-chave: Alheira; Enchidos fumados e curados; Bactérias ácido lácticas; Caraterísticas físico-químicas; Análise sensorial

ABSTRACT

Introduction: "Alheira" is a traditional Portuguese smoked sausage-like product that can be manufactured with different types of meat and bread. Biopreservation of foods has gained special prominence due to the possibility of naturally controlling the growth of pathogenic and spoilage microorganisms, with a growing interest in the use of lactic acid bacteria (LAB) and their bacteriocins.
Objectives: To ascertain the effect of adding fresh and dried starter LAB cultures (*Lactobacillus plantarum* ST153Ch) on the physicochemical and sensory characteristics of "Alheira".
Methods: All samples were produced at the industrial level. Sampling for analytical procedures was performed at 0, 15, 30, 45, 60, 75 and 90 days of storage at 4 °C. Physicochemical characteristics (moisture content, pH, water activity (a_w), instrumental hardness and adhesiveness, instrumental colour (L*, a*, b*)) and sensory evaluation, performed by 9 panellists regarding visual appearance, odour, texture and taste (11 attributes), were evaluated along the storage at 4 °C.
Results: Significant differences (p<0.05) were observed in all samples regarding moisture content, pH, a_w, instrumental hardness, adhesiveness and in colour parameters, during the storage period.
Conclusions: No significant differences in both inoculated "Alheira" samples compared to the control assay were found in sensory analysis until day 90, meaning that *L. plantarum* ST153Ch starter culture, fresh or dried, could be applied successfully until at least until day 75.

Keywords: "Alheira"; Cured smoked sausages; Lactic acid bacteria; Physicochemical characteristics; Sensory evaluation

RESUMEN

Introducción: "Alheira" es un embutido ahumado tradicional portugués que se puede producir con distintos tipos de carne siendo el pan un ingrediente clave. La biopreservación de los alimentos por la de la adicción de bacterias del acido láctico (BAL) y de sus bacteriocinas ha ganado especial destaque como forma de controlar naturalmente el crecimiento de microorganismos patógenos y de deterioro presentes en los alimentos.
Objetivos: Determinar el efecto de la adición de cultivos iniciadores de LAB (*Lactobacillus plantarum* ST153Ch) frescos y liofilizados en las características fisicoquímicas y sensoriales de "Alheira".
Métodos: Todas las muestras fueron producidas a nivel industrial. Los muestreos para todos los procedimientos analíticos fueron realizados en los días 0, 15, 30, 45, 60, 75, 90 de almacenamiento. Las características fisicoquímicas (humedad, pH, actividad del agua (a_w), dureza y adhesividad, color (CIE L*, a*, b*) y el análisis sensorial realizado a la apariencia visual, olor, textura y sabor (11 atributos), por un panel de 9 probadores, fueron evaluados a lo largo del almacenamiento en atmósfera modificada a 4 ° C.
Resultados: Se observaron diferencias significativas (p<0,05) entre todas las muestras en el contenido de humedad, pH, a_w, dureza, adhesividad y color a lo largo del almacenamiento.
Conclusiones: El panel sensorial no detectó diferencias significativas en la muestras de "Alheira" inoculada en relación al control hasta los 75 días de almacenamiento lo que posibilita la aplicación del cultivo *L. plantarum* ST153Ch al menos durante ese período.

Palabras Clave: "Alheira"; Embutidos ahumados/curados; Bacterias de ácido láctico; Características fisicoquímicas; Evaluación sensorial

INTRODUCTION

Consumer demand for foods without chemical additives is increasing forcing industry to meet consumers' interests, but food should remain safe and sensory changes should be minimized. In the last decade a great number of food products, named "natural", "free of additives", "biological", "probiotics", have been launched in the market (Zegler, 2017).
Application of bioprotective bacterial strains in foods has been shown to help reduce the amount of chemical preservatives as well as the intensity of the heat treatment, greatly improving the organoleptic and nutritional properties of food in addition to having control over many undesirable microorganisms, managing to increase the lifetime of food and increase the safety of the food itself (Vasquez, Suarez, & Zapata, 2009).
LAB is the dominant microbiota in refrigerated and vacuum-packed or AM-CO_2 meat products, and the use of these protective cultures has been studied as alternatives to the use of chemical additives to ensure food quality and safety (Holzapfel, Geisen, & Schillinger, 1995; Stiles, 1996; Mataragas, Drosinos, & Metaxopoulos, 2003; Vasquez et al., 2009). Some bacteriocins produced by LABs selectively inhibit certain high-risk bacteria in foods such as *L. monocytogenes*, without affecting the harmless microbiota. The efficacy of bacteriocins is often dictated by environmental factors, such as pH, temperature, food composition and structure, as well as the microbiota naturally present in the food (O'Sullivan, Ross, & Hill, 2002; Galvez, Abriouel, Lopez, & Ben Omar, 2007).
Today, a wide variety of sausages are produced, depending on their final and quality characteristics of a large number of variables related to raw materials, microbial population and processing conditions (Flores & Toldrá, 2011). The production of meat products is a long-standing tradition in the rural areas of Portugal, and these traditional meat products, with unique technological and sensorial characteristics, are very appellative for both, rural and urban consumers (Ferreira et al., 2007; Patarata, Judas, Silva, Esteves & Martins, 2008) and should be framed according to the current requirements of hygiene / health, from a perspective of consumer protection. This, not only values the organoleptic and nutritional properties of the products, but also increases the importance of food safety (Vieira da Silva, Teixeira, Hogg, & Couto, 2003).
The use of selected LAB strains as starter cultures strongly inhibited the bacterial growth of decomposition and left intact the organoleptic properties of fermented meat products, and thus LAB strains can be efficiently used to preserve meat products for quality purposes. Meat starter cultures are defined as "preparations that include live or inactive microorganisms that accumulate the desired metabolic activity in the meat" (Singh, Pathak & Verma, 2012). The starter cultures used in meat are strains of lactic acid bacteria (LAB), such as *Lactobacillus pentosus, L. casei, L. curvatus, L. plantarum, L. sakei, Pediococcus acidilactici, P. pentosaceus* (Singh et al., 2012).
Lactobacillus plantarum ST153Ch, a lactic acid bacteria (LAB), originally identified as *L. sakei* ST153Ch but later re-identified as *L. plantarum*, is an autochthonous strain isolated from a traditional Portuguese salami product - "Salpicão" (Todorov, Vaz Velho, Franco, & Holzapfel, 2013). The use of this strain combined with AM enriched in CO_2 reduced the number of cells of *Listeria* spp. in "Alheira" (Vaz-Velho et al., 2013), in sliced "Chouriço" (Jácome et al., 2014) and in smoked "Lombo" (Vaz Velho et al., 2015). Todorov et al., (2013), characterized the bacteriocin produced by *L. plantarum* (bacteriocin ST153Ch) as heat resistant, stable between pH 2.0 and 10.0 and showing higher levels during the stationary fermentation phase in the presence of 2% (w/v) D-Glucose. In addition, they have also shown that it is a safe strain that could contribute to the safety of fermented food products (Todorov, Franco & Wild, 2014).
Thus, this work aims to validate the use of a biocontrol process, using the autochthonous *L. plantarum* ST153ch, in the production, at a pilot scale, of "Alheira de Vitela", a traditional Portuguese smoked sausage.

1. MATERIALS AND METHODS

1.1 Sample preparation

"Alheira de Vitela" samples were manufactured in a meat plant according to traditional recipes and techniques. The ingredients used were as follows: Veal (35%), wheat bread (wheat flour, yeast and salt), pork, rooster meat, the cooking juice of meat, spices, onion, olive oil and salt. The sausage mixture, before stuffing, was divided into three batches: one batch was inoculated with *L. plantarum* ST153Ch fresh (2AlF), another batch with *L. plantarum* ST153Ch dried (2AlP) and the other one was non-inoculated (2AlC), to act as a control experiment. *L. plantarum* ST153Ch, fresh or dried, was added before stuffing, in order to reach ~10^6 CFU/mL in the final product. Dried culture was dissolved in 1.5 L of water and sucrose (6% w/v) and then added to the mixture. Fresh culture in 1.5 L of water was directly added to the mixture. Samples were prepared in triplicate. The samples of ''Alheira de Vitela" were cold-smoked by natural convection, in an artisanal smoker, by slow burning of *Quercus* spp. wood. After smoking and cooling, samples were packed under modified atmosphere (20 % CO_2 and 80 % N_2) and stored for 90 days at 4 °C. Sampling for analytical procedures was performed at 0, 15, 30, 45, 60, 75 and 90 days of storage.

1.2 Analytical procedures

Moisture content was determined by oven drying according to 1441 (ISO, 1997). Five g of each sample were heated at 103±2 °C until they reached constant weight (Vacucell MMM VU55, Germany). The results were expressed as % moisture content. Water activity (a_w) was measured in a portable a_w Pawkit meter (Decagon, EUA). The pH was measured directly using a pH meter (model CRISON pH 25+, Spain).

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Texture evaluation was carried out using a texture analyser TA-XTplus (Stable Micro Systems, UK). Textural parameters were measured using a Cylinder Probe P/10 (10 mm diameter) of surface contact. Sausage pieces of 1×1×2.5 cm (height × width × length) were compressed at a crosshead speed of 60 mm/min. Compression measurements were recorded with regard to hardness (expressed in N) and the adhesiveness (expressed in N/sec) force using the computer software Texture Exponent 32 (Stable Micro Systems, UK).
A portable colorimeter Minolta CR-300 (Konica Minolta, USA) was used to measure meat colour in the CIELAB space: lightness, L*; redness, a*; yellowness, b*.
A semi-trained 9-taster panel was used to evaluate sausage samples regarding to eleven sensory parameters: characteristic colour, brightness, meat binding, characteristic odour, strange odour, hardness, adhesiveness in the mouth, characteristic flavour, bitter taste, spicy flavour and acid taste. A scale of intensity of 1 to 13 (1-low intensity; 13-high intensity) was used and a score of 7 was previously established for the standard sample. The panellists were asked to classify the differences detected from this central point, except for the strange odour parameter, where the reference point of the sample was set as value 1. A general attribute of conformity with standard "Alheira", was set using a 5-point hedonic scale that allowed perceiving potential defects that were not expressed in the attributes. The score 3 was established as the limit of conformity, meaning that values lower than 3 correspond to detectable defective changes and values equal or higher than 3 correspond to a conforming product.

1.3 Statistical Analysis

All data were analysed statistically using an ANOVA procedure (IBM SPSS Statistics 25). The Tukey HSD test was used to investigate significant differences in physicochemical and sensory parameters (level of significance: $p<0.05$). A canonical variates analysis (CVA) was applied to sensory results to reduce the number of variables, selecting the few that best characterized the product in the sensory evaluation and to evaluate the separation of the groups analysed. Two variables were selected based on factor loadings modulus higher than 0.70: "characteristic colour" and "meat binding".

2. RESULTS AND DISCUSSION

The results of moisture, pH and water activity determinations throughout the 90 days of storage are summarized in Table 1. Significant differences in moisture values were found at 0, 15, 30 and 45 sampling days, with moisture being higher up to 30 days compared to the control sample. Inoculated samples presented lower pH values compared to the control, meaning that the inoculation of the starter cultures resulted in stronger acidification during the storage period.
In all samples the pH decrease during storage, pH being lower in the tested samples, as expected, due to LAB addition. The decrease of pH is related to an accumulation of organic acids, mainly lactic, because of carbohydrate breakdown during the fermentation (Casaburi et al., 2007; Essid & Hassouna, 2013; Lorenzo, Gómez, & Fonseca, 2014). This pH reduction, noticeable in all samples, is essential as it contributes to the inhibition of undesirable microorganisms, accelerates the red colour development of fermented sausages, affects taste and reduces the water binding capacity of proteins, ensuring the drying (Casaburi et al., 2007; Essid & Hassouna, 2013; Lorenzo et al., 2014).
Significant differences in water activity values were found at 15, 45, 60 and 90 days, the non-inoculated samples presenting lower aw values than both inoculated samples, but it must be pointed that moisture content of inoculated samples was also higher at day 0. Heterogeneity of samples is expected when dealing with a food matrix, such as "Alheira", where the diversity in its structural organization is noticeable at macroscopic level.

Table 1. Effect of inoculation starter cultures on moisture content, pH and water activity throughout the storage of "Alheira" at 4 °C.

		Storage (days)						
	Samples	0	15	30	45	60	75	90
Moisture content (%)	2AlC	56,68±0,10^{a}	56,65±0,38^{a}	56,67±0,20^{a}	56,06±0,17^{a}	56,84±0,42^{a}	56,21±0,35^{a}	56,64±0,1^{a}
	2AlF	57,47±0,58^{a,b}	57,75±0,48^{b}	57,71±0,36^{b}	57,49±0,26^{b}	55,75±1,99^{a}	57,09±0,42^{a}	57,33±0,1^{a}
	2AlP	57,84±0,30^{b}	58,02±0,34^{b}	58,53±0,21^{c}	57,83±0,28^{b}	57,92±0,21^{a}	57,64±0,99^{a}	57,46±0,6^{a}
pH	2AlC	5,92±0,07^{a}	4,90±0,04^{a}	4,52±0,01^{a}	4,34±0,04^{a}	4,62±0,04^{a}	4,44±0,11^{a}	4,79±0,17^{a}
	2AlF	5,69±0,02^{b}	4,88±0,04^{a}	4,46±0,01^{b}	4,25±0,02^{a}	4,43±0,07^{b}	4,53±0,06^{a}	4,55±0,02^{b}
	2AlP	5,84±0,02^{a}	4,85±0,01^{a}	4,53±0,01^{a}	4,27±0,04^{a}	4,40±0,02^{b}	4,38±0,06^{a}	4,47±0,02^{b}
Water activity	2AlC	0,87±0,04^{a}	0,96±0,01^{a}	0,96±0,01^{a}	0,95±0,01^{a}	0,94±0,03^{a}	0,94±0,01^{a}	0,90±0,01^{a}
	2AlF	0,93±0,02^{a}	0,97±0,01^{a}	0,98±0,01^{a}	0,99±0,01^{b}	0,98±0,02^{a}	0,98±0,02^{a}	0,97±0,05^{b}
	2AlP	0,92±0,01^{a}	0,98±0,01^{a}	0,98±0,00^{a}	0,99±0,01^{b}	0,99±0,01^{b}	0,96±0,02^{a}	0,98±0,02^{b}

a,b,c: Mean values in the same column (corresponding to the same days of storage) not followed by a common letter differ significantly ($p<0.05$).
Samples: 2AlC: control without starter culture; 2AlF: with *L. plantarum* ST153Ch fresh; 2AlP: with *L. plantarum* ST153Ch dried.

The results of the instrumental analysis of the texture and adhesiveness are shown in table 2. The texture is a predominant element of food quality and acceptability and is perceived from the sensory sensations of the physical properties of a material (Hussein, Razavi, & Emam-Djomeh, 2017). A decrease in hardness was found in all samples up to 60 days of storage when compared to the control (p<0.05). As reported by Benito et al., (2007) in a study with traditional Iberian sausages, starter cultures decreased hardness, probably due to its effect on protein hydrolysis. Regarding the adhesiveness, significant differences were found on 0, 75 and 90 days of storage (p<0.05). The sample inoculated with dried culture showed the highest values.

Table 2. Effect of the inoculated starter cultures on texture parameter throughout the storage of "Alheira" (means and standard deviations of ten replicates).

		Storage (days)						
	Samples	0	15	30	45	60	75	90
Hardness (N)	2AlC	5,73±0,64^{a}	4,45±0,81^{a}	5,03±0,55^{a}	3,93±0,66^{a}	2,38±0,23^{a}	4,23±0,79^{a}	4,90±1,10^{a}
	2AlF	4,49±0,56^{b}	3,74±0,80^{a}	4,66±0,76^{a}	3,57±0,49^{a,b}	2,77±0,42^{b}	4,36±0,60^{a}	3,50±0,67^{b}
	2AlP	5,44±0,72^{a}	4,06±0,59^{a}	3,25±0,97^{b}	3,05±0,58^{b}	2,46±0,16^{a}	4,59±1,03^{a}	3,78±0,45^{b}
Adhesiveness (N/sec)	2AlC	0,25±0,12^{a,b}	0,06±0,02^{a}	0,04±0,02^{a}	0,04±0,02^{a}	0,05±0,02^{a}	0,04±0,03^{a}	0,06±0,03^{a}
	2AlF	0,18±0,07^{a}	0,04±0,02^{a}	0,05±0,03^{a}	0,04±0,02^{a}	0,04±0,02^{a}	0,11±0,04^{b}	0,04±0,02^{a}
	2AlP	0,32±0,14^{b}	0,05±0,03^{a}	0,06±0,03^{a}	0,03±0,02^{a}	0,05±0,02^{a}	0,09±0,04^{b}	0,10±0,04^{b}

a,b,c: Mean values in the same column (corresponding to the same days of storage) not followed by a common letter differ significantly (p<0.05).
Samples: 2AlC: control without starter culture; 2AlF: with *L. plantarum* ST153Ch fresh; 2AlP: with *L. plantarum* ST153Ch dried.

The results of instrumental colour analysis are presented in Table 3.

Table 3. Effect of the inoculated starter cultures on colour parameter throughout the storage of "Alheira" (means and standard deviations of ten replicates).

		Storage (days)						
	Samples	0	15	30	45	60	75	90
L*	2AlC	49,81±1,38^{a}	43,49±2,60^{a}	51,86±4,22^{a}	57,53±2,93^{a}	52,76±2,76^{a}	54,14±4,37^{a}	60,16±2,77^{a}
	2AlF	49,58±2,74^{a}	41,51±4,73^{a}	50,73±4,50^{a}	54,26±5,73^{a}	52,56±3,58^{a}	56,12±3,05^{a}	57,61±1,89^{b}
	2AlP	49,14±2,09^{a}	41,90±3,60^{a}	50,87±4,78^{a}	52,88±4,03^{a}	52,12±5,00^{a}	54,49±2,87^{a}	57,91±2,43^{a,b}
a*	2AlC	17,09±2,63^{a}	16,05±3,16^{a}	12,63±2,86^{a}	13,92±2,19^{a}	11,89±1,51^{a,b}	13,41±1,09^{a}	12,46±0,86^{a}
	2AlF	15,57±1,19^{a}	16,32±2,80^{a}	13,58±2,71^{a}	12,45±1,41^{a}	13,00±1,32^{a}	14,48±2,03^{a}	13,69±1,12^{b}
	2AlP	15,53±1,49^{a}	15,37±1,48^{a}	11,80±2,22^{a}	12,98±1,64^{a}	11,26±1,06^{b}	13,79±1,25^{a}	13,45±1,01^{b}
b*	2AlC	16,38±2,57^{a}	15,98±2,15^{a}	19,68±5,11^{a}	22,69±1,77^{a}	25,22±1,44^{a}	28,07±1,97^{a}	27,13±2,84^{a}
	2AlF	15,86±1,74^{a}	15,83±2,53^{a}	21,21±2,92^{a}	21,67±2,36^{a}	26,87±1,56^{a}	29,91±2,46^{a}	29,02±2,62^{a}
	2AlP	15,76±1,49^{a}	15,81±2,85^{a}	19,60±5,37^{a}	20,95±1,92^{a}	25,69±2,77^{a}	28,36±2,24^{a}	27,39±0,93^{a}

a,b,c: Mean values in the same column (corresponding to the same days of storage) not followed by a common letter differ significantly (p<0.05).
Samples: 2AlC: control without starter culture; 2AlF: with *L. plantarum* ST153Ch fresh; 2AlP: with *L. plantarum* ST153Ch dried.

Colour is one of the most important quality attributes of sausages, since it affects overall quality (Essid & Hassouna, 2013). The addition of *L. plantarum* ST153Ch initially did not affect the colour parameters L* (brightness), a* (red) and b* (yellow), but significant differences were found from 75 days of storage.

Results of sensory analysis with respect to the 11 attributes showed that most of the attributes for both inoculated samples were similar to the control in the seven sampling periods. This is in accordance with what Jácome et al. (2014) observed, which is that the application methodology of LAB in this type of product did not affect the sensory properties. Only significant differences (p<0.05) were found in the "acid taste" parameters at 45 days (Suplementary Table S1).

Barros, D. B., Sobrosa, C., Pinheiro, R., Fonseca, S. & Vaz-Velho, M. (2018). Effect of addition of a starter cultures on physicochemical and sensory properties of "Alheira", a smoked sausage-like product. *Millenium*, 2(7), 39-48.
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The "Alheira" sensory profile is also represented in figure 1 and figure 2, on a scale of intensity of the main descriptors. Regarding the attributes "brightness", "hardness" and "characteristic flavour" in the both inoculated samples showed lower values when compared to the control and only sample inoculated with fresh *L. plantarum* showed lower "characteristic odour". For the "adhesiveness", "spicy, acid and bitter taste" the result showed some increased along storage period in both LAB conditions but only "acid taste" presented significant differences (p<0.05), as already mentioned.

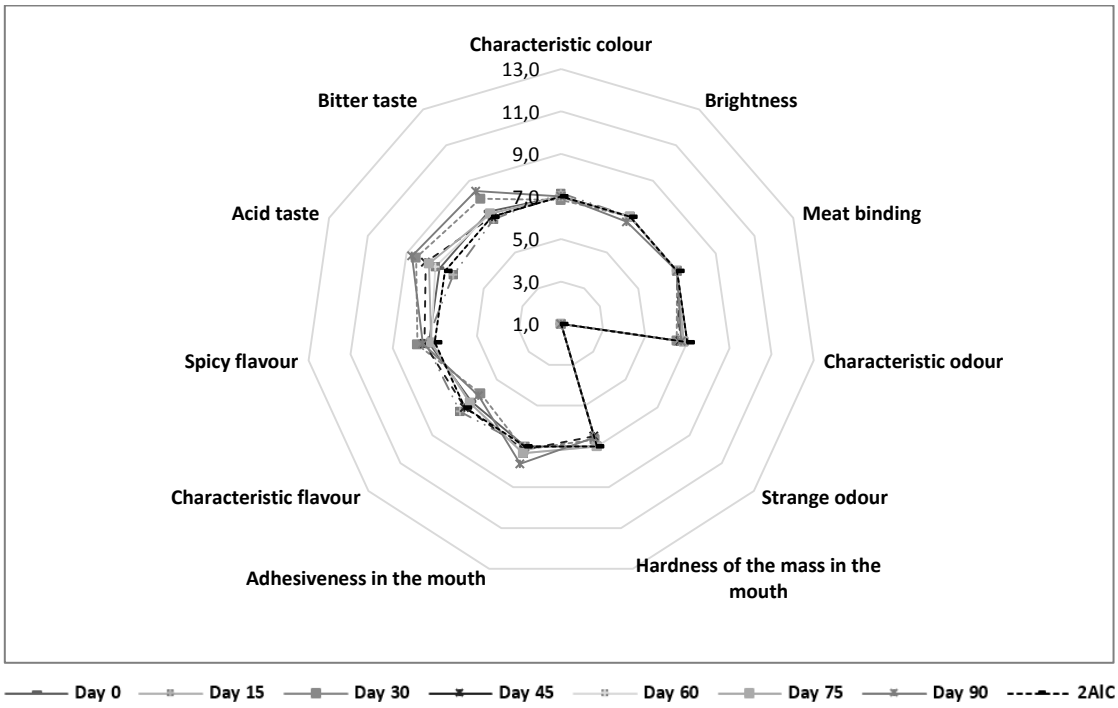


Figure 1. Sensory profile of "Alheira" during storage at 4 °C in an intensity scale of the main descriptors considered in a QDA for 2AlF with *L. plantarum* ST153Ch fresh. 2AlC: control without starter culture.

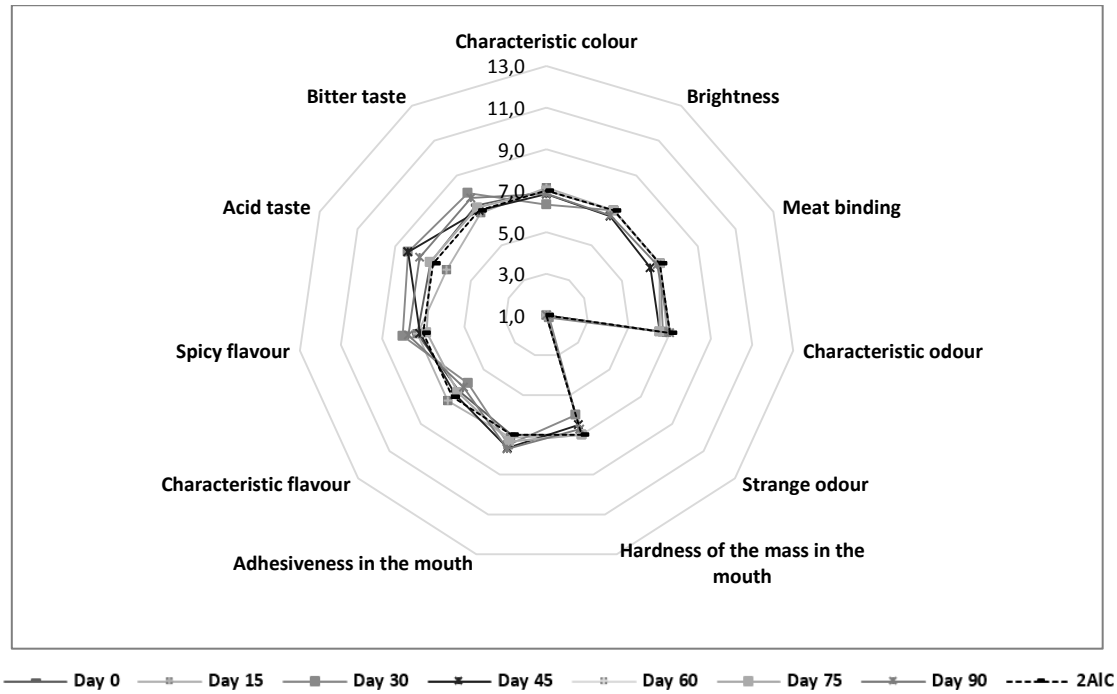
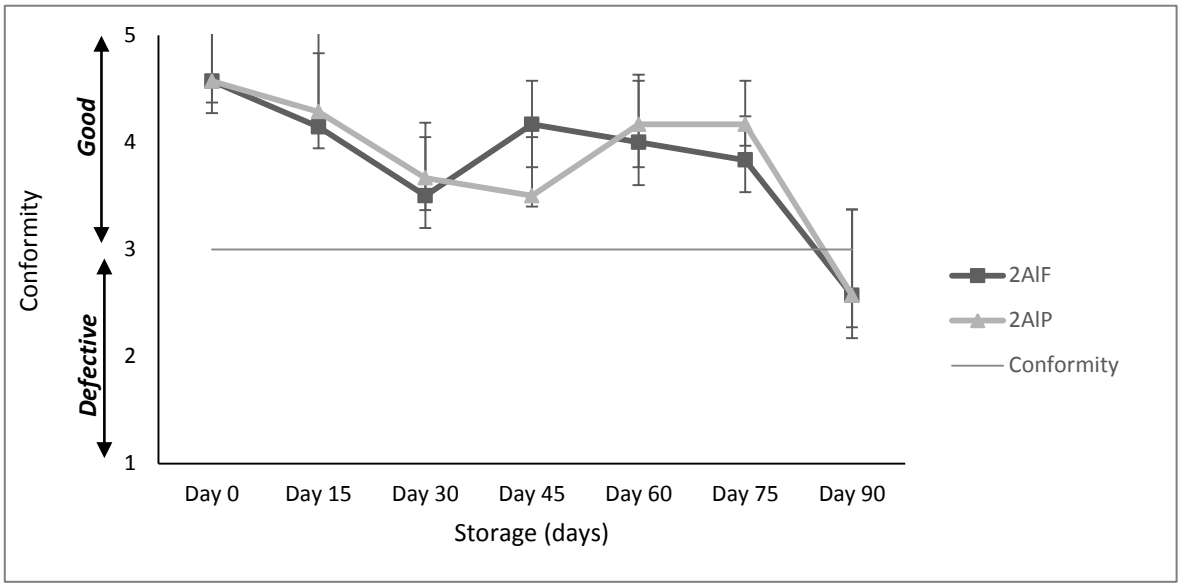


Figure 2. Sensory profile of "Alheira" during storage at 4 °C in an intensity scale of the main descriptors considered in a QDA for 2AlP with dried *L. plantarum* ST153Ch. 2AlC: control without starter culture.

Regarding the conformity parameter (Figure 3), the panellists considered that at day 90 the product is no longer conform as it obtained a score lower than 3. However, the commercial shelf-life of "Alheira" is 60 days and, in the present study, at day 75, the product was considered conform, this meaning a 15 days extension of its shelf-life.
The sensory characteristics of the final product are the result of a complex interaction of physicochemical, biochemical and microbiological processes with role in the formation and equilibrium of chemical compounds and in the modification of molecules responsible for texture and appearance (Ciuciu Simion, Vizireanu, Alexe, Franco, & Carballo, 2014). The present sensory analysis aimed to compare the effect of the addition of a fresh and lyophilized LAB culture on the sensory properties of "Alheira de Vitela".



(b)

Figure 3. Conformity variations over the storage period of "Alheira" samples (2AlF: with *L. plantarum* ST153Ch fresh; 2AlP: with *L. plantarum* ST153Ch dried) (mean ± standard deviation).

Figure 4 displays CVA applied at the sensory analysis data of the two inoculated samples of "Alheira" studied at 0, 15, 30, 45, 60, 75 and 90 days. As it can be seen dispersion of points representing any "Alheira"/time is very high, due to the lack of agreement among judges panellist that might be related with the natural sample heterogeneity. Loadings of each variable to each CV after factor structure matrix from two canonical roots were performed using the 11 original variables in order to determine which aspects were of greatest importance in "Alheira" characterization. Two variables were selected based on factor loadings modulus higher than 0.70: "characteristic colour" and "meat binding". The Eigen value of the second canonical variate (CV2) is inferior to 1 and therefore differences observed between the top and the bottom of all figures are not significant.

Barros, D. B., Sobrosa, C., Pinheiro, R., Fonseca, S. & Vaz-Velho, M. (2018). Effect of addition of a starter cultures on physicochemical and sensory properties of "Alheira", a smoked sausage-like product. *Millenium*, 2(7), 39-48.
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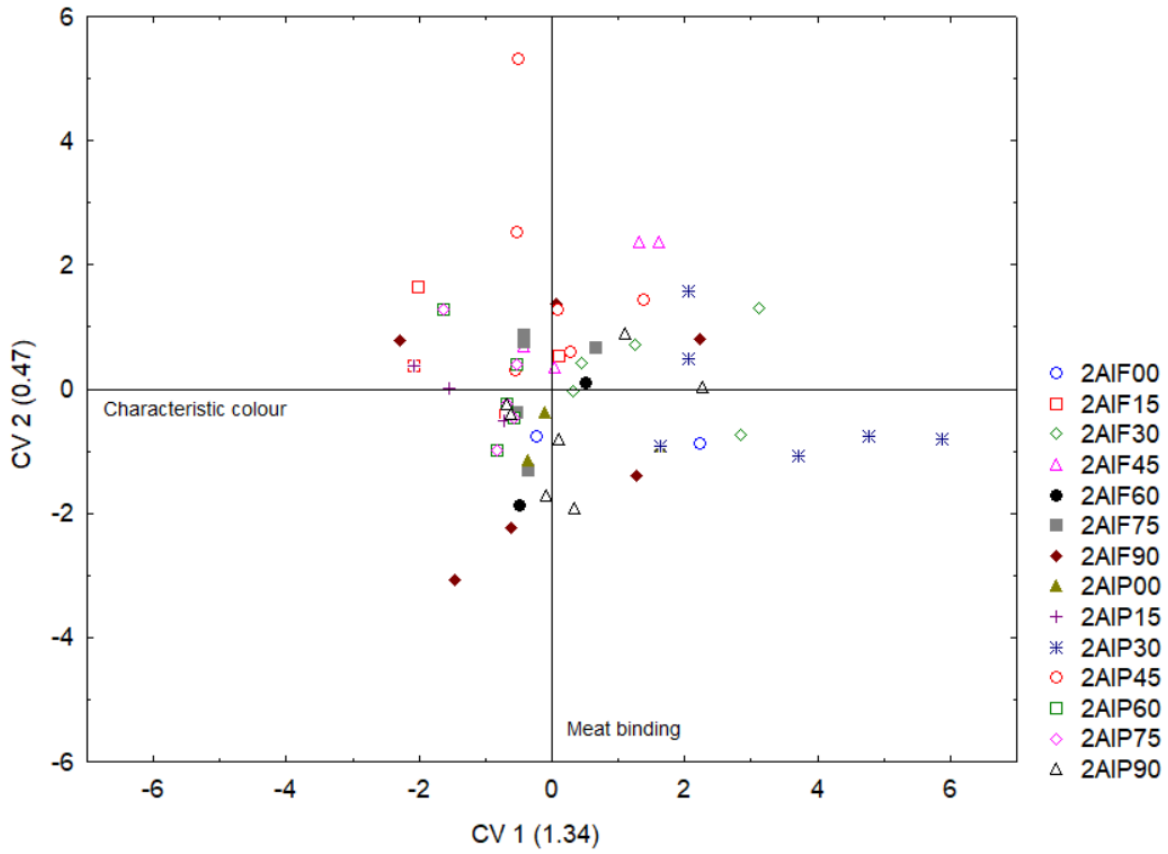

Figure 4. Canonical variance analysis projection applied to the dimensions obtained from the 2 variables selected sensorial analysis data of "Alheira" with case projection (storage time) (2AIF: with *L. plantarum* ST153Ch fresh; 2AIP: with *L. plantarum* ST153Ch dried).

Studies on the effect of starter cultures and packaging methods on amino acid profile and eating quality characteristics of pork ham, showed that the use the starter cultures brought about desirable changes regarding to all the traits studied (Gogoi, Borpuzari, Borpuzari Hazarika, & Bora, 2015), Pork ham is a more homogeneous food matrix compared to "Alheira" and the dispersion of the LAB cultures might be more distributed throughout the samples.
As for the role and use of LAB in the quality of dry-fermented meat products, LAB take part in the coagulation of muscle proteins by acidifying the batters, which results in increased slice stability, firmness, and cohesiveness of the final product. Besides, they contribute to the flavour of the final product through the formation of noticeable acidic and vinegary (acetic acid) tastes. Moreover, the existing acidic conditions may increase the activity of cathepsin D, which is responsible for muscle proteolysis (El Adab, Essid, & Hassouna, 2014; Laranjo, Elias, & Fraqueza, 2017).

CONCLUSIONS

Overall, no significant differences were found between application methodologies (fresh or dried LABs), hence industry might be able to choose the most appropriate technique according to their manufacture process. On the other hand, it was also verified that at 90 days the panellists report acid taste and spicy flavour and samples were scored below the conformity level, therefore this technique has changed organoleptic characteristics. The extension of 15 days of shelf-life was achieved but further assays must be performed to optimize the sensory properties and to assure an extension of shelf life up to 90 days.

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INFLUÊNCIA DA TEMPERATURA DA ESTUFA DE SECAGEM NA COMPOSIÇÃO QUÍMICA DE UM MALTE DE CEVADA GREGO E PROPRIEDADES DO SEU MOSTO

INFLUENCE OF KILNING TEMPERATURE ON CHEMICAL COMPOSITION OF A GREEK BARLEY MALT AND ITS WORT PROPERTIES

LA INFLUENCIA DE LA TEMPERATURA DE SECADO EN LA COMPOSICIÓN QUÍMICA DE UNA MALTA DE CEBADA GRIEGA Y LAS PROPIEDADES DE SU MOSTO

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RESUMO

Introdução: É reconhecido que o caráter e a qualidade do malte são obtidos durante a secagem. Além disso, as mudanças ocorridas durante a secagem afetam a qualidade do esmagamento e do mosto.
Objetivos: Até agora, na Grécia, para a produção de malte, são comumente usadas outras variedades de cevada, em vez de nativas. Assim, esta pesquisa tem como objetivo avaliar o efeito da temperatura de estufa na melhoria da capacidade de maltagem para cultivo da cevada grega.
Métodos: Os grãos de cevada foram maltados no Food Process Engineering Laboratory - Pilot Plant of ATEITh (Thessaloniki). A cevada maltada foi primeiro seca a 40-45 °C (malte seco) e depois seca em estufa. A secagem da cevada germinada foi realizada a três temperaturas diferentes (80, 90 e 100 °C, por 6h), a fim de produzir três maltes diferentes. A cevada, malte seco e malte foram analisados quanto ao teor de humidade, cinzas, proteína e seus respetivos teores em β-glucana, teor de extrato do malte, cor, densidade e viscosidade específica. Também foram determinados o total de açúcares fermentáveis, bem como o seu perfil. Finalmente, os maltes foram comparados com um malte comercial.
Resultados: Fatores como a humidade do malte, o teor de β-glucana, a cor do malte, o extrato de malte e a viscosidade específica foram significativamente afetados pelo processo de secagem em estufa. Pelo contrário, os teores de cinzas e proteínas no malte não foram significativamente afetados. O malte produzido a partir da cultivar de cevada grega mostrou um teor de β-glucana, gravidade específica e valores de viscosidade específicos semelhantes aos da amostra comercial.
Conclusões: O presente estudo revelou que a qualidade do malte e do mosto da cultivar de cevada grega (Seirios) pode ser significativamente melhorada pela otimização da temperatura de estufa.

Palavras-chave: malte de cevada; teor de β-glucana, estufa, qualidade de mosto, HPLC

ABSTRACT

Introduction: It is recognized that the character and the quality of the malt is obtained during kilning. Moreover, the changes occurring during kilning affect mashing and wort quality.
Objectives: Till now, in Greece, for the malt production other barley varieties rather than native ones are commonly used. Thus, this research aims to evaluate the effect of kilning temperature in improving malting ability of a Greek barley cultivar.
Methods: Barley kernels were malted in the Food Process Engineering Laboratory - Pilot Plant of ATEITh (Thessaloniki). The malted barley was first dried at 40-45°C (dry malt) and then kilned. The kilning of germinated barley was performed at three different temperatures (80, 90 and 100°C for 6h), in order to produce three different malts. Barley, dry malt and malted kernels were analysed for their moisture, ash, protein and β-glucan content whereas their respective worts, for extract content of the malt, colour, specific gravity and specific viscosity. The total fermentable sugars as well as their profile were also determined. Finally, the malts were compared with a commercial malt.
Results: Factors such as malt moisture, β-glucan content, malt colour, malt extract and specific viscosity were significantly affected by the kilning process. Contrary, the ash and protein contents in the malt were not significantly affected. The malt produced from the Greek barley cultivar showed β-glucan, specific gravity and specific viscosity values similar to the commercial sample.
Conclusions: The present study revealed that the malt and wort quality of the Greek barley cultivar (Seirios) can be significantly improved by optimizing the kilning temperature.

Keywords: barley malt; β-glucan content, kilning, wort quality, HPLC

RESUMEN

Introducción: Se reconoce que el carácter y la calidad de la malta se obtienen durante el secado. Además, los cambios que ocurren durante el secado en estufa afectan la maceración y la calidad del mosto.
Objetivos: Hasta este momento, en Grecia, se usan habitualmente otras variedades de cebada en lugar de las nativas para la producción de malta. Por lo tanto, esta investigación tiene como objetivo evaluar el efecto de la temperatura del secado en estufa en la mejora de la capacidad de malteado de un cultivar de cebada griego.
Métodos: Los granos de cebada fueron malteados en el laboratorio de Food Process Engineering - Pilot Plant de ATEITh (Thessaloniki). La cebada malteada se secó primero a 40-45 ° C (malta seca) y luego se tostó. El secado en estufa de la cebada germinada se realizó a tres temperaturas diferentes (80, 90 y 100 ° C durante 6 h), con el fin de producir tres maltas diferentes. La cebada, la malta seca y los granos malteados se analizaron por su contenido de humedad, cenizas, proteínas y β-glucano, mientras que sus respectivos mostos, por el contenido de extracto de la malta, el color, la gravedad y la viscosidad específica.

También se determinaron los azúcares fermentables totales, así como su perfil. Finalmente, las maltas se compararon con una malta comercial.
Resultados: Factores como la humedad de la malta, el contenido de β-glucano, el color de la malta, el extracto de malta y la viscosidad específica fueron afectados significativamente por el proceso de secado en estufa. Al contrario, los contenidos de cenizas y proteínas en la malta no se vieron afectados significativamente. La malta producida a partir del cultivar de cebada griego mostró β-glucano, gravedad específica y valores de viscosidad específicos similares a la muestra comercial.
Conclusiones: : El presente estudio reveló que la calidad de malta y mosto del cultivar de cebada griego (Seirios) puede mejorarse significativamente al optimizar la temperatura del secado en estufa.

Palabras Clave: malta de cebada, el contenido de β-glucano, secado en estufa, calidad de mosto, HPLC

INTRODUCTION

Barley (*Hordeum vulgare* L.) is classified among the most important cereals in terms of production quantity and cultivation areas. The annual world production reached over 141 million tons in 2016 (FAOSTAT, 2018). Barley shows a great diversity in the morphological form and is cultivated across a wide range of production areas in the world (Horsley & Hochhalter, 2004). Malting has been used to impart distinctive flavours and colours in barley. Brewing is the most common area of use, in order to get fermentable sugars for alcoholic fermentation. Another potential use of malting is to increase the bioavailability of nutrients and change flour texture (Bamforth & Barclay, 1993; Stanca, Gianinetti, Rizza, & Terzi, 2016).
Malting procedure includes three steps: steeping, germination and kilning. During steeping, the barley is soaked in water until reach the defined moisture content. The aim of steeping is the moisture content of the grain will reach the required level for germination to begin. During germination, hydrolytic enzymes are synthesized by the aleurone cell. The content of hydrolytic enzymes (α-amylase, endo-β-glucanase and proteinase) increase in amount during the second or third day after steeping (MacLeod, Duffus, & Johnston, 1964). Kilning is heating of grain with increasing temperature regime above 50°C in order to obtain desired properties for the malters. The desired properties include enzyme survival, removal of moisture for stabilization, removal of raw flavours, development of malty flavours and colour (Bamforth, 2003). The kilning of malt is not simply a drying process but also a chemical process in which the character and quality of the malt are generated (Johnston, 1954). The reaction of sugars and amino acids induced by heating during the kilning process and wort boiling leads to the formation of melanoidins via the Maillard reaction responsible for imparting colour to beer (Bamforth, 2003).
Generally, all barley cultivars could be used to produce malt. However, different properties of the barley should be taken into account in order to obtain high quality malt. The barley should be of high vitality to be used for malt since it is obligatory for the germination process. Moreover, it should have a chemical composition that makes it suitable for having high yield during brewing. Too much protein content lowers the extract yield and can give a beer that is not clear or may slow down the start of germination. On the other hand, too little protein results in lower enzyme activity and slows growth of the yeast in the brewery. In fact, there is evidence that uneven protein content represents quality problems in malt (Palmer, 2000).
β-Glucan and arabinoxylans, the major constituents of barley endosperm cell walls, are hydrolysed during malting, allowing release of the entrapped starch granules (Briggs, 1998). As a consequence, soluble β-glucan and arabinoxylans that are released in the wort have the ability to increase its viscosity, due to their physicochemical properties, such as molecular weight and concentration (Lazaridou, Biliaderis, Micha-Screttas, & Steele, 2004; Skendi, Biliaderis, Izydorczyk, Zervou, & Zoumpoulakis, 2011; Skendi, Biliaderis, Lazaridou, & Izydorczyk, 2003).
Differences in β-glucan content and composition depend on the variety and growing conditions (Skendi et al., 2003). The content of β-glucan is lower, is more soluble and possibly of lower molecular in malt than in barley (Teixeira, Nyman, Andersson, & Alminger, 2016). It was found that modification of the steeping conditions during malting can possibly preserve β-glucan content of barley malt (Rimsten et al., 2002). The degradation of the starch during mashing of the malt as well as other carbohydrate polymers by endogenous enzymes produced during malting of barley results in a vast diversity of fermentable sugars. The final composition of wort is very complex and mainly attributed to the enzyme activity and the process control (MacGregor, Bazin, Macri, & Babb, 1999). The major fermentable sugars is maltose, with lesser quantities of glucose, maltotriose, sucrose and fructose (Bamforth, 2003).
The aim of the present work was to study the extent to which chemical characteristics of a Greek barley variety could be modified by using different kilning temperatures, on brewing. For this purpose, β-glucan, protein, moisture and minerals were investigated in laboratory-scale malting experiments for Seirios barley cultivar followed with comparison with a commercial barley cultivar used for brewing.

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1. METHODS

1.1 Materials and Chemicals

The barley kernels, cultivar Seirios (SB) (two-rowed), were obtained from the ELGO-DEMETER, Institute of Plant Breeding and Genetic Resources (Thessaloniki, Greece). Commercial malt (CM) (in the form of kernels), was generously donated by the "Macedonian Thrace Brewery S.A.".

All reagents used for the determination of the fermentable sugars were of analytical grade purity. The standard of D-(-)-fructose was purchased from Riedel-deHaen (Seelze, Germany), the D-(+)-glucose, sucrose and maltose were from Merk KGaA (Darmstadt, Germany), whereas the maltotriose was obtained from Megazyme (Bray, Ireland). Acetonitrile was obtained from Chem-Lab NV (Zedelgem, Belgium). For the HPLC measurements ultrapure water was used. For the determination of the β-glucan content in the unmalted barley and malts a Megazyme β-glucan assay kit (Bray, Ireland) was used.

1.2 Malting and mashing

Barley kernels (SB) were malted in the Food Process Engineering Laboratory - Pilot Plant of ATEITh (Thessaloniki). For the malting of the samples the method used involves steeping the barley at 15°C following several circles of soaking and air rests for 2 days, then the barley was evenly spread out on trays and allowed to germinate at 15°C. After germination, barley was dried (pre-kilning) at 40-45°C in order to obtain the dry malt (SDM) in an air circulatory electrically heated oven. Then, the pre-kilned sample was divided in three sub -samples, each one kilned for 6 hours at a different kilning temperature (80°C, 90°C and 100°C) in order to obtain three different malt samples (SM80, SM90 and SM100, respectively). Before analysis, barley and malt kernels were ground to pass through a 0.8mm sieve on a mill (Falling Number AB Type 120 grinder, S-12611, Stockholm, Sweden). The analyses were performed in both untreated barley and malted samples.

The milled samples of barley and malt were used to obtain mash. The wort was performed as reported to the congress mash procedure according to the EBC method 4.5.1 (2004) in the Cereal Laboratory of ATEITh (Thessaloniki). There were obtained the following worts: from unmalted barley (SB-W), from dry malt (SDM-W), from commercial malt (CM-W) and from malts prepared at 80, 90 and 100°C (SM80-W, SM90-W and SM100-W).

1.3 Malt and wort analyses

The protein content of unmalted, commercial malt and malted barley samples were determined using the EBC-methods (3.3.1 for barley and 4.3.1 for malt). The factor used to convert nitrogen to protein was 6.25. β-Glucan content was measured following the assay procedure for barley (EBC Method 3.10.1) and malt (EBC Method 4.16.1) described in the Megazyme β-glucan assay kit (K-BGLU, Megazyme International, Ireland), respectively. Moisture content was resulted by drying milled samples in an oven at 105°C till constant weight. Ash content was determined by using AACC method 08-01 (1983) approved method. All analyses were made at least in duplicate.

The mash was filtered according to EBC-method 4.5.1, through filter paper (Whatman® prepleated qualitative filter paper, Grade 597 1/2) into graduated cylinders. The filtered wort was used to measure colour, viscosity, specific gravity and malt extract. Congress wort viscosity was measured according to EBC-method 8.41 whereas the malt extract was calculated based on the EBC-method 4.5.1.

1.4 HPLC analysis of fermentable sugars in wort

The obtained wort samples (filtered ones) were immediately frozen and then freeze-dried. For the analysis of the fermentable sugars, a portion of dried sample was diluted in ultrapure water and then filtered through a 0.22μm nylon syringe filter (Simplepure). All the samples were daily prepared.

Fermentable sugars were determined by high-performance liquid chromatography (HPLC). The HPLC consisted in a SpectraSYSTEM liquid chromatography system (Thermo Finnigan, San Jose, CA) equipped with SpectraSYSTEM SCm1000 degasser, a Marathon series IV SSV pump, a refractive index detector (ERC-7515A, ERC Inc), a chromatographic column (Separon SGX NH2 5μm, size: 4.6 × 250mm RigasLab, Thessaloniki, Greece) and a rheodine injector equipped with 20μl loop.

A quantity of 100mg of each standard fermentable sugar (fructose, glucose, sucrose, maltose and maltotriose) was added to a 10mL volumetric flask and dissolved in ultrapure water to obtain the stock solution. Then, six different concentrations were obtained by diluting stock solution with ultrapure water in order to prepare the standard curve. An isocratic elution mode was employed with the mobile phase consisting of acetonitrile/water (85:15, v/v) at a flow rate of 2.3mL/min. The detector temperature was 35°C and the chromatographic column temperature was 30°C.

1.5 Statistical analysis

Analytical procedures were carried out at least in duplicate and the means and standard deviation of all results were calculated. The data are shown as the mean and standard deviation of the mean (SD). ANOVA and Duncan's post hoc tests were used to evaluate the difference between each kilning condition and untreated barley. A two-tailed Pearson's test was used to evaluate

the existing correlations. Statistical significance was established when $P < 0.05$. Statistical analysis was performed using SPSS Statistics software.

2. RESULTS AND DISCUSSION

2.2 Variation in the malt composition

Drying of green malt represent an important step during which there are stopped different modifications in the structure of the barley and make malt stable for storage ensuring in the same time the survival of enzymes for the mashing step. Variation in the moisture content of the malt is shown in Figure 1. The final moisture 14.38% in the dried malt was the result of the moisture reduction during first drying at 40-45°C of the green malt. The reduction was lower than the one generally recommended for the green malt (about 12%) when the water in the kernels is firmly "bound" (Briggs, Hough, Stevens, & Young, 1981). Briggs reports that in European lager malts the moisture values vary 5-6% with some high-diastatic power malts having moisture contents of around 8% (Briggs, 1998). In general, the moisture content of the malts obtained at 80, 90 and 100°C is significantly lower (5.72, 7.45 and 5.63%, respectively) than that of the unmalted barley (10.70%). The obtained values are within the limits observed for the commercial malts (Briggs, 1998).

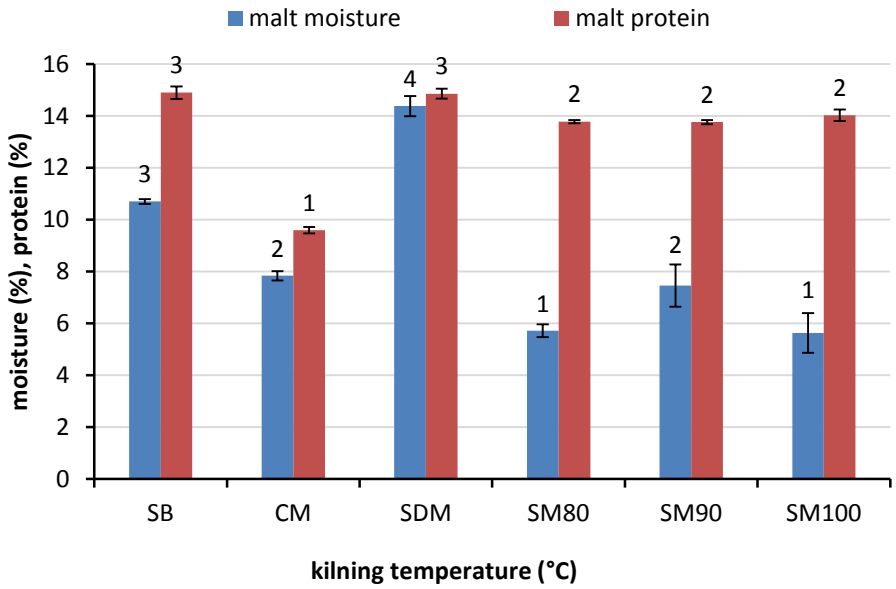

Figure 1. Variation of the moisture and protein content (dry basis) in barley, dried malt and malts.

According to the literature barley for malting should have a protein content of from 9.5 to 11.5% (dry basis)(Ingvordsen et al., 2016; Pettersson & Eckersten, 2007). The cultivar Seirios has a much higher protein content (14.90%). This value is much higher than the values reported from Plant Breeding and Genetic Resources Institute for the same cultivar (10.5-11.5%). This deviation may be due to the very adverse condition of growing observed in the growing season (2016). Malting barley with high protein content results in lower extracts. Grain protein content was negatively related with the grain size and grain yield (Magliano, Prystupa, & Gutiérrez-Boem, 2014). Generally it is believed that a barley with a high protein content will give a malt with a lower yield of extract than a malt from a barley having a lower protein content (Briggs, 1998).

During malting, proteins are mainly solubilized and hydrolysed into smaller peptides and amino acids through a range of proteolytic enzymes (Baxter, 1981; Jones, Marinac, & Fontanini, 2000), but the absolute crude protein content was not expected to change significantly. There was a small relative decrease in protein content for all malted samples (Figure 1) as a result of respiration of carbohydrates. Since the protein-rich roots and shoots are removed from the malt there is a decrease in protein content. No difference due to the different kilning temperature (80, 90, 100°C) was observed in the protein content. The similar protein content in the dried malt compared to the unmalted barley may be related to partial removal of the roots in the dried malt due to its high moisture content.

There is observed a slight decrease in the ash content of the malt during malting (Figure 2). This is possibly because of the solubilization and removal of some metals during malting. Moreover, the values observed in the commercial barley are similar to those observed in the unmalted barley and malted samples.

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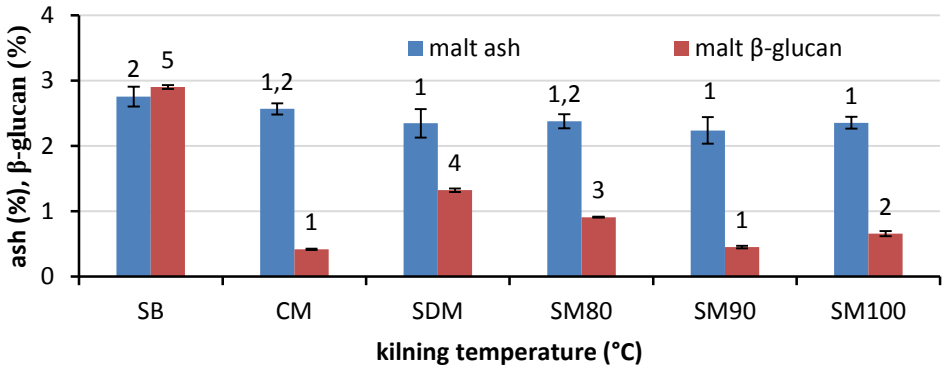

Figure 2. Variation of the ash and β-glucan content (dry basis) in barley, dried malt and malts.

Presence of high amount of β-glucan is found responsible for giving rise to a filtration problem in the brewery causing chill haze, on the maturing of beer (Gupta, Abu-Ghannam, & Gallaghar, 2010). Changes in β-glucan levels during malting are related to a great extent to β-glucanase activity, which is found responsible for the depolymerization of β-glucan (Etokakpan, 1993).
The content of β-glucan decreased significantly during malting (Figure 2). The decrease was higher in the malt kilned at 90°C; this value being similar to that of commercial malt. It was reported that β-glucanases, that develop during the germination of barley, are rapidly and extensively destroyed in kilning (Bamforth & Martin, 1983). It is observed that the decrease in the β-glucan content is not stopped on the first drying step (40-45°C). It continues during kilning step suggesting that β-glucanases are not deactivated if low drying temperatures were applied and continue to be active also in the dried kernels.

2.2 Variation in the wort parameters

Congress mashing is generally used for routine malt analysis. Figure 3 and 4 highlight the parameters which were determined during congress mashing.
Barley β-glucans are recognized as important factors that determine wort viscosity and beer filtration rates (Stewart, Freeman, & Evans, 2000). The wort of unmalted barley exhibited a specific viscosity value of 9.58 (Figure 3). This is possibly due to the high concentration of β-glucans present in the wort. All the worts from the malted samples showed lower specific viscosity than the wort from unmalted barley. The values of specific viscosity varied in the range 0.45-0.58 (Figure 3). It was observed that the dried malt (SDM) and malt kilned at 90°C (SM90) produces wort with the lowest specific viscosity among the malts, possibly due to the low content of β-glucan and presence of the high content of the degrading enzymes that break down β-glucans. Kilning temperature 100°C inactivated part of the enzymes responsible for the decrease of the specific viscosity since the respective wort showed the highest specific viscosity among the malts. The wort from malt produced at 90°C showed specific viscosity values similar to that made from commercial malt.
Correlation analysis performed between the β-glucan content and the specific viscosity revealed a very strong (0.934) positive relation at the 0.01 level (2-tailed). This relation explains the very high specific viscosity value observed in the barley wort as well the variation in the specific viscosity of the worts.

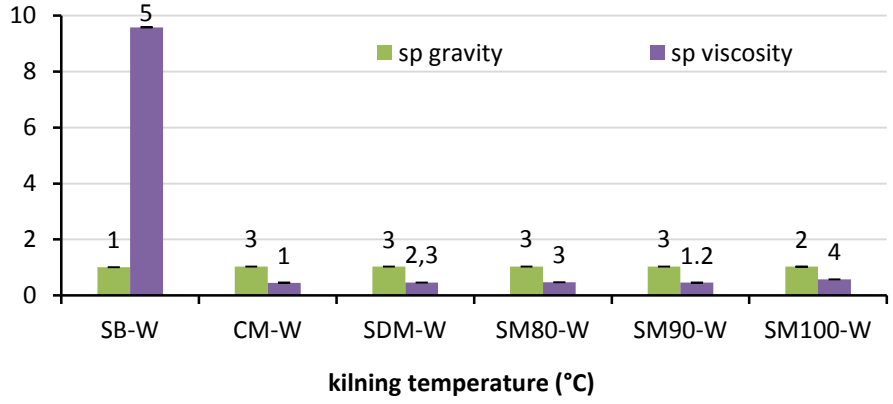

Figure 3. Variation of the specific gravity and specific viscosity in the worts obtained from barley, dried malt and malts.

According to Briggs et al., the specific gravity of the extract is a measure of the "preformed soluble substances" present in the malt (Briggs, Boulton, Brookes, & Stevens, 2004). The specific gravity is related with the presence of fermentable sugars present in the wort. Generally, higher the specific gravity higher the amount of fermentable sugars in the wort. Similarly, the higher the specific gravity the higher concentration of wort solids in the solution (Briggs et al., 2004). The specific gravity of the wort from dried malt and barley kilned at 80 and 90°C was similar to the commercial barley sample whereas the malt kilned at 100°C showed lower value (Figure 3). In the case of malt kilned at 100°C the low value of specific gravity may be related to the lower content of the degrading enzymes that reduce the amount of starch transformed in fermentable sugar, as well as to the negative effect of high specific viscosity in the extraction of the fermentable sugars.
The weight of extract in the wort is calculated assuming that the dissolved extract solids change the specific gravity to the same extent as sucrose (Briggs et al., 2004). The malt extract is calculated from the specific gravity using tables that relate the strengths of sucrose solutions with their specific gravities. As expected, malt extract values among the samples showed the same trend as the values of the specific gravity with values ranging from 64.91 to 77.99% (Figure 4). Worts from malts kilned at 80 and 90°C showed statistically similar values to the wort from commercial malt. Extracts of pale malts determined by the EBC method are usually in the range 77-83% whereas the typical ranges for darker malts are 75-78% (Briggs et al., 2004).
In general, colour specifications are set based upon the final product being produced. It was observed that malt processing can have a large impact on colour development; increasing modification or kilning temperatures can lead to more intense wort colour (Bamforth, 2006). Indeed, increasing the kilning temperature increased the colour of the wort (Figure 4). The wort colour of dried malt and malt kilned at 80°C was found to be lighter than that of the commercial malt wort.

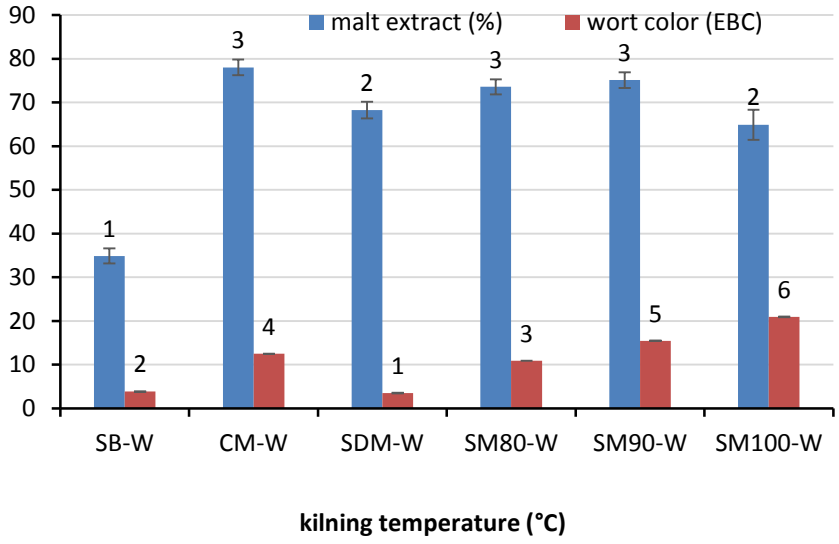

Figure 4. Variation of the malt extract and colour in the worts obtained from barley, dried malt and malts.

2.3 Variation in the fermentable sugars in wort

In general, the amount of fermentable sugars present in the obtained congress wort decreases with increasing of the kilning temperature (Figure 5A). The values for the total fermentable sugars varied in the range 4.3 to 20.76%. The wort prepared with the dry malt and the malt kilned at 80°C showed similar content of fermentable sugar per liter as the wort with the commercial barley malt. As expected the unmalted barley released less than 5g/L fermentable sugars in the respective wort.
Standard brewery wort consists of the following : sucrose, fructose, glucose, maltose and maltotriose, together with dextrin material (He et al., 2014). The main component of the total fermentable sugars was maltose with values ranging from 58.6% to 72% followed by glucose at the range 14.2 to 21.7% (Figure 5B). The maltose/maltotriose ratio varied between 6 and 11. The literature reports that maltose and maltotriose are the most abundant sugars (He et al., 2014). Fructose represents the compound with the lowest concentration (1.8-2.9%). It is evident that the amount of sucrose in the wort of malted samples of Seirios variety was more than the double of the sucrose content in the wort from the commercial malt.

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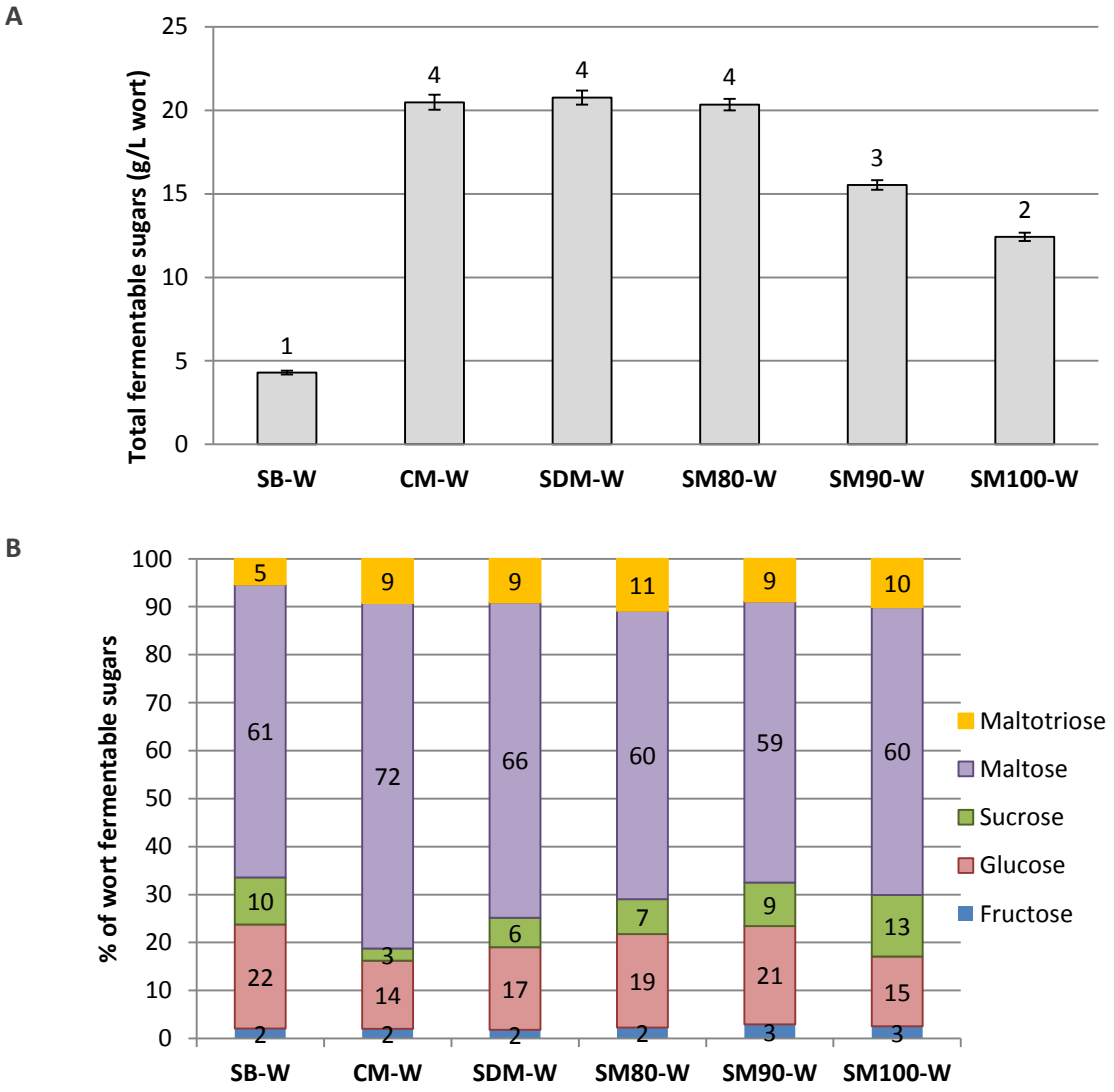

Figure 5. (A) Content of the total fermentable sugars present in the wort and (B) percentage of the five fermentable sugars in the commercial malt (CM), unmalted barley (SB), and three different malts SM80, SM90 and SM 100 obtained by kilning at 80, 90 and 100°C, respectively.

CONCLUSIONS

This study elucidates the impact of kilning temperature on chemical composition of the malt in terms of moisture, ash, protein and β-glucan content, as well as the respective wort characteristics specifically specific viscosity, specific gravity, wort colour and malt extract. Moreover, it was studied the profile of the fermentable sugars present in the wort.

Based on the results of this study, it can be concluded that prolonged kilning at 40°C does not necessary causes inactivation of β-glucanase activity. The content of β-glucan was decreased substantially at a kilning temperature of 90°C. Possibly the presence of high moisture could favour the β-glucanase activity reducing further the β-glucan content and producing wort with specific viscosity, specific gravity and malt extract similar to that of the commercial sample. However, the total fermentable sugars were decreased with the kilning temperature. Although wort samples SM80 and SM90 showed similar specific gravity and malt extract, kilning at 80°C produced wort with a content of total fermentable sugars similar to that of commercial malt. This suggests that at 90°C the presence of high solid matter can be explained by the presence as well as the amount of the enzymes that survived the kilning process. The combination of both factors may be responsible for the production, through fractional hydrolysis during wort production, of soluble components able to give higher specific gravity. As expected the wort colour was darker with increasing kilning temperature.

In general, by altering the kilning temperature it was possible to obtain malt from a Greek barley that reassembles the chemical composition and characteristics of wort from the commercial malt. Further optimization of kilning conditions, could introduce potential to ensure survival of the enzymes.

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AVALIAÇÃO SENSORIAL DA CARNE DE SUÍNOS MACHOS INTEIROS CRIADOS COM DIFERENTES CONDIÇÕES DE ALIMENTAÇÃO E ALOJAMENTO

SENSORY EVALUATION OF MEAT FROM ENTIRE MALE PIGS RAISED WITH DIFFERENT FEEDING AND HOUSING CONDITIONS

EVALUACIÓN SENSORIAL DE LA CARNE DE CERDOS MACHOS ENTEROS CRIADOS CON DIFERENTES CONDICIONES DE ALIMENTACIÓN Y ALOJAMIENTO

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RESUMO

Introdução: O aroma a varrasco é um odor/flavour desagradável presente na carne de porcos macho não castrados, que é causado principalmente por dois compostos: a androstenona e o escatol. A incidência do odor a varrasco é de especial importância quando se considera o uso desta carne para a produção de produtos cárneos.
Objetivos: Este estudo visa a avaliação das características organoléticas da carne de porcos macho não castrados criados em condições específicas com o objetivo de reduzir ou eliminar o odor a varrasco.
Métodos: Foi analisada carne da barriga de porcos não castrados criados em seis condições diferentes (maneio normal *versus* maneio melhorado) e alimentação com níveis diferentes de inulina adicionada (0%, 3% e 6%). A análise descritiva quantitativa (QDA®) foi usada para avaliação organolética das amostras que foram previamente cozidas e apresentadas em frasco fechado ao painel composto por 10 provadores treinados, que avaliaram o odor e flavour a escatol e androstenona, a textura e o sabor doce na carne.
Resultados: Os resultados demonstraram haver diferenças significativas (p<0.05) entre as diferentes condições, nos parâmetros odor e flavour a escatol e androstenona e textura.
Conclusões: Como esperado, o odor a varrasco foi mais intenso nas amostras com a condição maneio normal e sem inulina adicionada. Tendo em conta estes resultados pode-se concluir que a adição de inulina tem efeitos positivos quando conjugada com condições de maneio melhoradas.

Palavras-chave: odor a varrasco; androstenona; escatol; análise sensorial

ABSTRACT

Introduction: Boar taint is an off-odour/off-flavour found in meat from entire male pigs due to two main compounds: androstenone and skatole. The incidence of boar taint is of concern when considering the use of entire males for pork meat production.
Objectives: This study aims at evaluating sensory characteristics of meat from entire male pigs raised under specific conditions in order to reduce or eliminate the boar taint.
Methods: Belly meat from entire male pigs raised under six different conditions (normal housing *versus* improved housing) and feeding with different levels of added inulin (0%, 3% and 6%) was analysed. A Quantitative Descriptive Analysis (QDA®) methodology was applied to samples, previously cooked and presented in closed jars, and the panel, composed by 10 trained panellists, was asked to assess odour and flavour of skatole and androstenone, texture and sweet flavour.
Results: Significant differences (p<0.05) were found between samples concerning skatole and androstenone odour and flavour, and texture compared to control samples.
Conclusions: As expected, the boar taint was stronger in samples where no addition of inulin and no improved conditions were applied. It can be concluded that the inulin addition into pig feed have positive effects when conjugated with better housing conditions.

Keywords: boar taint; skatole; androstenone; sensory analysis

RESUMEN

Introducción: El olor a verraco es un olor/flavour desagradable presente en la carne de cerdos macho no castrados, que es causado principalmente por dos compuestos: la androstenona y el escatol. La incidencia del olor a verraco es de especial importancia cuando se considera el uso de esta carne para la producción de productos cárnicos.
Objetivos: Este estudio se refiere a la evaluación de las características sensoriales de la carne de cerdos macho no castrados creados en condiciones específicas con el fin de reducir o eliminar el olor a verraco.
Métodos: Se analizó la carne de la barriga de cerdos no castrados creados en seis condiciones diferentes (manejo normal *versus* manejo mejorado) y alimentación con niveles diferentes de inulina añadida (0%, 3% y 6%). El análisis descriptivo cuantitativo (QDA®) fue utilizado para evaluar las muestras que fueron cocidas y presentadas en frasco cerrado al panel compuesto por 10 probadores entrenados, evaluando el olor y flavour del escatol y androstenona, la textura y el sabor dulce en la carne.
Resultados: Los resultados mostraron diferencias significativas (p<0.05) entre las diferentes condiciones, comparado con el control, en los parámetros olor y flavour a escatol y androstenona y en la textura.
Conclusiones: Como se esperaba, el olor a verraco fue más intenso en las muestras con la condición normal y sin inulina añadida. Teniendo en cuenta estos resultados se puede concluir que la adición de inulina tiene efectos positivos cuando se combina con condiciones de manejo mejoradas.

Palabras Clave: olor a verraco; androstenona; escatol; análisis sensorial

INTRODUCTION

In the European Union, pork production stakeholders have declared to ban surgical castration by 2018 for animal welfare reasons which has posed a challenge to all stakeholders involved in the pork production chain (Morlein et al., 2015). Male piglets are castrated primarily to prevent the development of the objectionable sensory perceived odour or flavour of boar taint in their carcasses (Fredriksen, Johnsen, & Skuterud, 2011; Gunn et al., 2004; Wauters et al., 2017). Available evidence suggests that castration at any age is painful (Gunn et al., 2004) and this practice is now questioned in an increasing number of countries due to animal welfare concerns (Fredriksen et al., 2011). Raising entire male pigs has some economic advantages as boars possess the advantage of superior growth over castrates, a lower feeding demand, generally leaner carcasses, and compared to castrates less feed is needed in order to achieve the same final weight, whereby also fewer nutrients are emitted to the environment (Morlein et al., 2015; Wauters et al., 2017). However, slaughtering entire male pigs implies the risk of having carcasses with the so-called boar taint (Aaslyng, Broge, Brockhoff, & Christensen, 2015) posing a risk to the entire pork supply chain therefore being a significant barrier to the banning of the undesirable practice of piglet castration (Mathur et al., 2012). Boar taint is described as a penetrating 'animal', 'urine', 'faecal' or 'sweat' like unpleasant odour which becomes especially intense when pork is cooked (Mathur et al., 2012), and is mainly associated with the presence of skatole and androstenone, but animal tissues contain varying levels of other compounds, such as indole and other steroids, that can influence the perceptions of the main contributors of boar taint (AnnorFrempong, Nute, Whittington, & Wood, 1997; Morlein et al., 2016). Skatole (3-methylindole) is a metabolite derived from the amino acid tryptophan produced in the lower gut by intestinal bacterial flora, and androstenone (5α androst-16-en-3-one) is a steroid produced in the testis (Aldal et al., 2005; Chen, Zamaratskaia, Andersson, & Lundstrom, 2007; Lunde et al., 2010). Levels of skatole are lower in castrates and gilts than in entire male pigs and the reason has not been fully elucidated (Aldal et al., 2005). High levels of skatole in pig meat can be effectively reduced by diet and keeping animals free of faecal contamination (Garrido et al., 2016). Due to the lipophilic characteristics of skatole and androstenone, redistribution from blood to fat tissue is easily occurring with prolonged accumulation in fat tissues (Aldal et al., 2005; Wauters, Vercruysse, Aluwe, Verplanken, & Vanhaecke, 2016). Sensory analysis is one of the most common tools used in meat studies (Garrido et al., 2016), and because androstenone and skatole are predominantly released when fat is heated, the sensory evaluation is carried out using heating methods (Trautmann, Meier-Dinkel, Gertheiss, & Morlein, 2016). There is evidence that management practices such as batch rearing, use of particular feed ingredients and prevention of pigs wallowing in excrement may contribute to the reduction of boar taint (Gunn et al., 2004). Several studies (Aluwe et al., 2013; Backus et al., 2016; Bilić-Šobot, Čandek-Potokar, Kubale, & Škorjanc, 2014; Byrne, Thamsborg, & Hansen, 2008; Hansen et al., 2008; Kjos, Overland, Fauske, & Sorum, 2010) have shown that fermentable carbohydrates, such as the inulin obtained from chicory, were effective in reducing the concentration of skatole in the hindgut. A possible explanation is that chicory inulin reduces the number of *Enterococcus* spp. which are important for the production of amino acid l-tryptophan in the colon (Bilić-Šobot et al., 2014). Housing conditions and genetic selection can also have a favourable effect on boar taint reduction (Backus et al., 2016). The production of pork from entire male pigs in enriched housing conditions seems also to be a promising alternative to castration, as improved husbandry aims at high standards of animal welfare and elimination of mutilations (Holinger, Fruh, & Hillmann, 2015).

The aim of this research was to study the sensory effect of improved housing and different feeding conditions in entire male's meat.

1. METHODS

The experimental design included a total of 60 entire male pigs of a crossbreed (progeny of Large White x Landrace dams sired by Pietrain boars), raised in a pig farm in Vila Nova de Poiares, Coimbra, Portugal. The same commercial diet, *ad libitum* access, was given to the animals until 5.5 months age. Then, pigs were separated into six treatment groups, varying the type of housing and percentage of inulin added in feeding portions, as described in Table 1. All received commercial feed (produced by Cevargado) 2.8 kg per pig per day and the diet of four groups included 3% or 6% inulin, for 2 months prior to slaughter. Improved housing conditions consisted in a larger area, easier access to water and environmental enrichment accessories (toys). The shipment and transportation of the improved housing group to the slaughterhouse was carried out with procedures aimed at reducing stress. Pigs were slaughtered in the same day, and carcasses were transported to a meat processing factory, where meat cuts were kept at - 18 °C.

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Table 1 – Housing conditions and inulin feed composition.

Pen	Housing	Added inulin in feed (%)	Number of pigs
A	Normal	0	10
B	Normal	3	10
C	Normal	6	10
D	Improved (+Care)	0	10
E	Improved (+Care)	3	10
F	Improved (+Care)	6	10

Samples were coded as N0% (control), N3%, N6%, C0%, C3% and C6%, where "N" means normal housing, "C" improved housing and 0, 3 and 6 correspond to percentage of added inulin in animal feed.

1.1. Sample preparation

For this experiment, the selected meat cut was the belly. On the day prior to the sensory analysis, 8 samples of meat, corresponding to the six groups (plus two replicates to evaluate repeatability) were randomly selected and placed to thaw at 4 °C. Samples were cut into cubes (4 cm) and cooked in boiling water until internal temperature of meat reached 80 °C. They were immediately closed in glass jars with its broth and transferred to the sensory analysis laboratory and kept in a 60 °C bath in the cabinet booths.

1.2. Sensory analysis

The sensory evaluation was conducted in a sensory evaluation laboratory that has eight individual booths and an adequate ventilation system, with positive pressure atmosphere. The sensory panel consisted of 10 assessors, selected on the basis of their sensory performance and afterwards trained for boar taint evaluation. This training process focused on the ability to detect both androstenone and skatole, adapting a procedure from Garrido et al. (2016), in which they presented to panellists standards using Vaseline oil media as carriers of androstenone and skatole. A quantitative descriptive analysis (QDA®) methodology was selected to evaluate samples. Sensory attributes were defined previously in group as recommended by ISO:6658 (2005) and after consensus, anchors and scales were set and panellist trained with standards adapted to each anchor. Pre-defined attributes such as: androstenone odour and flavour, skatole odour and flavour, sweet flavour and texture were rated on the agreed intensity scale. Generally, odour/flavour attributes, scales ranged from 1 to 10, where for score 1 was *absent* and score 10 was *very intense*, for sweet flavour anchors were *no sweet* to *very sweet* and for texture, intensity scale anchors were *very soft/moisty* to *fibrous/dry*. A total of 8 glass jars, with three-digit codes, containing meat samples were presented in a random order to the panellists, that were instructed to pause at least 5 minutes between each sample. Panellists were free to check previous opened jars in order to compare samples and correct their evaluation if necessary. Within the 8 samples 2 of them were replicates in order to evaluate repeatability.

1.3. Statistical analysis

In order to investigate differences, it was performed variance analysis (One-way ANOVA) with repeated measures followed by *post hoc* Fisher's Least Significant Difference (LSD). The groups of treatments, housing conditions and feeding conditions were set as the independent variables and the sensory attributes (androstenone odour, skatole odour, androstenone flavour, skatole flavour, sweet flavour and texture) defined as dependent variables. Significant differences were set at $p<0.05$.
Canonical Variates Analysis (CVA) with judges as replicates, was carried out to discriminate groups of samples. Principal Component Analysis (PCA) based on correlations using all cases using the means was carried out to check if there were patterns in the dataset. These analyses were carried out using SPSS v.25.0 software.

2. RESULTS AND DISCUSSION

In this study, cooked belly meat from uncastrated pigs raised under different levels of housing and feeding, was analysed to verify if there was sensory perception of different levels of androstenone and skatole.
There is little data available concerning boar taint evaluation with regard to assessor reliability (Morlein et al., 2016). However, to evaluate the repeatability of panellists, two samples of the same condition groups were served twice with different codes. Results of this evaluation showed that panellists had a 1.2 mean deviation of its scores. Canonical Variates Analysis (CVA) was carried out to find out if the panel data discriminate groups of samples. As seen in Figure 1, although groups are very next to each other it is possible to verify that there are some patterns in their distribution, namely by type of housing or value of added inulin. It is also important to take into consideration the fact that in biological samples not only androstenone and skatole levels

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vary a lot but also that there are other factors affecting this scent, for example, the fat content and matrix itself also differ between animals (Morlein et al., 2016).

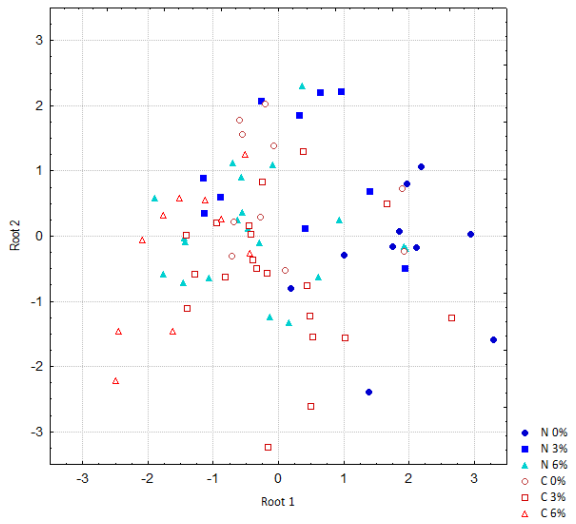

Figure 1. Canonical Variates Analysis graph for panellists. N-normal housing; C-improved housing. 0, 3 and 6% is the value of added inulin in feed.

Results showed that panellists discriminate meat samples from animals with inulin addition in its feeding portions. Table 2 shows the scores of sensory evaluations performed by panellists, and it is possible to outline that only attribute "sweet flavour" showed no significant differences. Concerning to androstenone odour, panellists stated that it was immediately perceived after the opening of the jar. They have noticed that meat from pigs that had received normal treatment (0% inulin added, normal housing) had the most intense androstenone odour ($p<0.05$), and in meat from pigs with improved housing (+Care) and 6% of inulin added was less perceived, having the lowest score ($p<0.05$). In the other three attributes (skatole odour, androstenone flavour and odour), although there were some significant differences between groups ($p<0.05$ in all cases), the stronger sample was always the control (Normal 0%).

Table 2 – Cooked belly meat sensory attributes (mean and standard deviation) scored by a trained panel, by condition (AND=androstenone; SKA=skatole). Different letters in the same row indicate a statistical difference ($p<0.05$) using LSD test.

Attributes	Condition groups					
	Normal 0% n=10	Normal 3% n=10	Normal 6% n=20	+Care 0% n=10	+Care 3% n=20	+Care 6% n=10
AND odour	6.5 ± 1.4^{a}	4.4 ± 1.9^{b}	4.0 ± 1.5^{b}	4.8 ± 1.9^{b}	4.5 ± 2.0^{b}	2.4 ± 1.3^{c}
SKA odour	6.4 ± 1.5^{a}	2.8 ± 1.7^{cd}	3.7 ± 1.9^{bcd}	3.0 ± 1.8^{c}	4.7 ± 1.7^{b}	2.7 ± 1.2^{d}
AND flavour	5.3 ± 1.7^{a}	2.9 ± 1.9^{c}	3.0 ± 1.3^{c}	3.6 ± 2.2^{abcd}	4.6 ± 2.8^{ab}	2.7 ± 0.9^{cd}
SKA flavour	5.5 ± 1.7^{a}	2.5 ± 1.4^{c}	2.8 ± 1.0^{c}	2.5 ± 1.4^{c}	3.8 ± 2.2^{bc}	1.9 ± 0.9^{c}
Sweet flavour	5.1 ± 0.9^{a}	5.1 ± 0.8^{a}	4.8 ± 0.9^{a}	4.7 ± 1.3^{a}	4.8 ± 1.4^{a}	4.5 ± 1.3^{a}
Texture	4.8 ± 1.5^{bc}	4.6 ± 2.0^{bc}	6.5 ± 1.8^{a}	5.4 ± 1.6^{b}	5.3 ± 1.5^{b}	5.9 ± 1.3^{abc}

Concerning texture, samples with the scored with highest values were the ones with 6% of added inulin in feed, meaning that panellist found this meat more fibrous and dry.
Although +Care condition had always lower boar taint scores, ANOVA analysis applied only to the housing conditions revealed no significant differences between attributes. On the other hand, ANOVA applied to inulin levels showed that androstenone odour was the strongest in 0% inulin samples ($p<0.05$). By the contrary, addition of 6% of inulin leads to the lower scores of androstenone odour and flavour perception ($p<0.05$) as well as skatole odour and flavour. In meat samples with 3% of inulin no significant differences were found concerning skatole odour and flavour. Similar findings were also reported by Byrne et al. (2008) and Hansen et al. (2008), where chicory (inulin is mostly extracted from chicory roots) reduced boar taint since odour and

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flavour of manure related to skatole and urine associated to androstenone. Aluwe et al. (2013) and Kjos et al. (2010) also stated that chicory feed supplemented in boar feed decreased skatole concentration in adipose tissue.
In order to study the relation between attributes and to investigate patterns within the samples and pigs raising conditions, a PCA was carried out (Figure 2). Boar taint variables (skatole flavour/odour and androstenone flavour/odour) have the highest values on PC1, which represents 74,75% of the total data. From this output, it is possible to observe that N0% samples are projected to the end of the left side in PC1 axis meaning that is highly correlated with the highest scores of boar taint related attributes. In the opposite side (from the centre to the right) of the PCA output are projected the samples from animals fed with 6% of inulin, being perceived as more fibrous and dry (texture). PC2 does not have great meaning in this analysis.

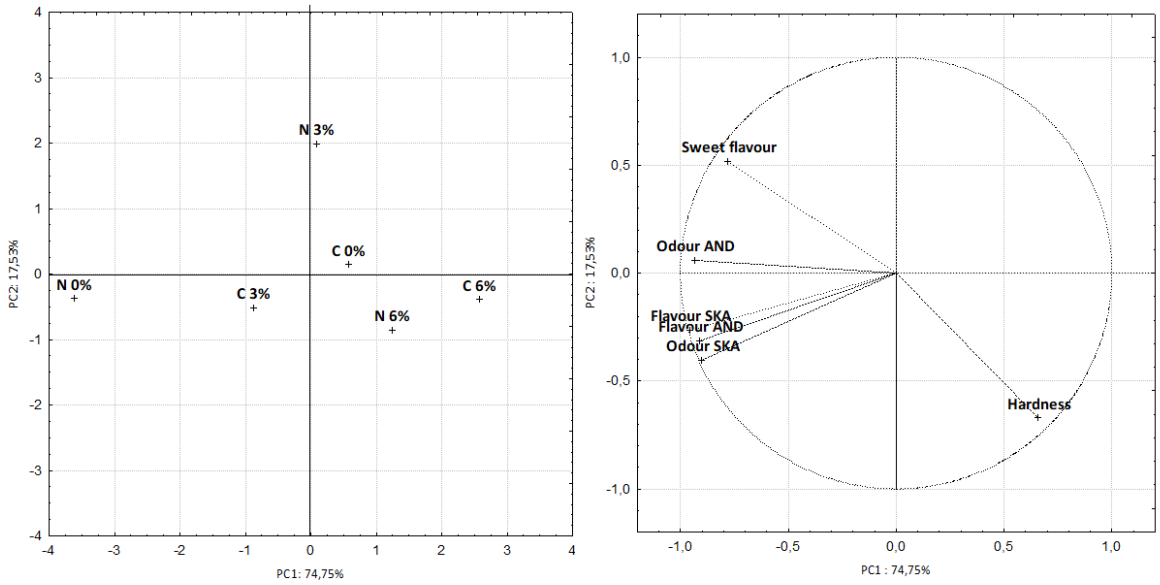

Figure 2. Principal component analysis of sensory evaluation: score plot for the mean classification of condition groups (left) and loading plot of different attributes (right). N-normal housing; C-improved housing. 0, 3 and 6% is the value of added inulin in feed.

CONCLUSIONS

From this study, it is possible to conclude that samples of belly meat from entire male pigs raised under different condition were considered different. When submitted to sensory analysis by a trained panel it was perceived some differences mainly related to boar taint. The main effect was the reduction of boar taint caused by addition of inulin in the pigs feed. Despite of housing conditions had no significant effect on reduction of boar taint, androstenone and skatole flavour and odour were stronger in samples where no improved conditions were applied and no inulin added. It can be concluded that the effect of inulin addition into pig feeding portions have positive effects when conjugated with better housing conditions.

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O EFEITO DA MALTAGEM SOBRE OS CRISTALITOS E MICROESTRUTURA NO CULTIVO DE CEVADA GREGA USANDO DIFRAÇÃO DE RAIOS-X E ANÁLISE MICROSCÓPICA.

THE EFFECT OF MALTING ON THE CRYSTALLITES AND MICROSTRUCTURE IN GREEK BARLEY CULTIVAR USING X-RAY DIFFRACTION AND MICROSCOPIC ANALYSIS

EL EFECTO DEL MALTEADO SOBRE LOS CRISTALITOS Y LA MICROESTRUCTURA EN EL CULTIVO DE UNA CEBADA GRIEGA USANDO DIFRACCIÓN DE RAYOS X Y ANÁLISIS MICROSCÓPICO.

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RESUMO

Introdução: A maltagem era geralmente usada para produzir açúcares a partir do amido e consequentemente permitir a fermentação alcoólica. A variação na microestrutura e cristalinidade do amido afeta sua solubilização de água e a sua hidrólise pelas enzimas.
Objetivos: A microestrutura do amido é explorada para entender e possivelmente modificar o processo de maltagem, se necessário, de uma variedade de cevada grega. Para resolver o problema, foram utilizados uma combinação de métodos de microscopia e de inspeção de difração de raios-X para avaliar a variação da morfologia dos grânulos e o grau de cristalinidade do amido.
Métodos: O efeito da maltagem na microestrutura do amido de cevada foi investigado para uma cultivar de cevada grega (Seirios). As sementes de cevada foram fornecidas pelo ELGO-DEMETER, Instituto de Criação de Plantas e Recursos Genéticos (Thessaloniki, Grécia). A maceração foi realizada a 14 ° C (vários círculos de imersão e arejamento) até a cevada atingir o teor de humidade desejado. Então a cevada mergulhada foi deixada a germinar a 15 ° C. A germinação foi interrompida por secagem a 40-45 ° C, durante pelo menos 20 h (malte seco). O malte foi obtido por secagem durante 6 horas a 100 ° C. A cevada, malte seco e malte foram moídos para passar por uma tela de 0,8 mm antes de serem analisados. As fotografias de microscopia confocal com coloração vermelha do Congo foram usadas para identificar a variação na morfologia dos grânulos de amido. Além disso, foi realizada a análise de difração de raios-x da farinha de cevada, malte seco e moagem de malte. Finalmente, a análise dos difractogramas de raios-X foi realizada para calcular a cristalinidade relativa e o tamanho dos cristalitos de amido.
Resultados: Os resultados demonstraram variações na morfologia dos grânulos de amido. As fotografias de microscopia confocal revelaram que os grânulos de amido na cevada eram redondos, maiores, lisos e granulares, e que o malte seco e o malte pareciam menores e mais alongados com arranhões na superfície. As fotografias coradas da microscopia confocal mostraram o início dos danos na superfície dos grânulos do amido. Os difractogramas de Raios-X revelaram que a cristalinidade do amido de cevada aumentou durante a produção de malte seco e depois diminuiu durante a secagem, mas permaneceu maior do que o amido de cevada nativa.
Conclusões: A maltagem sob as condições especificadas afetou a morfologia dos grânulos de amido da variedade Seirios, bem como a cristalinidade do mesmo, sugerindo a degradação parcial do amido durante o período de maceração e germinação, bem como durante a secagem.

Palavras-chave: cevada; amido; malte; XRD; microscopia;

ABSTRACT

Introduction: Malting was generally used to produce fermentable sugars from starch in order to permit alcoholic fermentation. Variation in the starch microstructure and crystallinity affects its water solubilisation as well as and its breakdown from the enzymes
Objectives: The starch microstructure is explored in order to understand and possibly modify the malting process of a Greek barley variety if needed. To address the issue, a combination of microscopy and X-ray diffraction inspection methods were used to evaluate the variation of the starch granule morphology and the degree of crystallinity of starch.
Methods: The effect of malting on the microstructure of barley starch was investigated for one Greek barley cultivar (Seirios). The barley seeds were provided from ELGO-DEMETER, Institute of Plant Breeding and Genetic Resources (Thessaloniki, Greece). The steeping was performed at 14°C (several soaking and aerating circles) until barley reached the desired moisture content. Then the steeped barley was allowed to germinate at 15°C. The germination was stopped by drying at 40-45°C for at least 20h (dry malt). The malt was obtained by kilning for 6 hours at 100°C. The barley, dry malt and malt were milled to pass through a 0.8mm screen before being analysed. Light microscopy photographs with Congo red staining were used to identify variation in the starch granule morphology. Moreover, the x-ray diffraction analysis of the barley meal, dry malt and malt millings were obtained. Finally, the analysis of X-ray diffractograms was performed in order to calculate relative crystallinity and the crystallite size of the starch.
Results: The results demonstrated variations in the morphology of the starch granules. The stained light microscopy photographs revealed that the starch granules in barley were round, greater, smooth, and granular, and that of the dry malt and the malt appeared smaller and more elongated with scratches on the surface. The stained confocal microscopy photographs showed the beginning of the starch damage on the surface of the granules. X-Ray diffractographs revealed that the crystallinity of the barley starch was increased during dry malt production and then decreased during kilning but still remained greater than the native barley starch.

Conclusions: Malting under the specified conditions, affected the morphology of the starch granules of Seirios variety as well as the crystallinity of the starch suggesting the partial degradation of the starch during steeping and germination as well as during kilning.

Keywords: barley; starch; malting; XRD; microscopy;

RESUMEN

Introducción: El malteado se usaba, en general, para producir azúcares fermentables a partir del almidón a fin de permitir la fermentación alcohólica. La variación en la microestructura y cristalinidad del almidón afecta su solubilidad en agua y su degradación de las enzimas.
Objetivos: La microestructura del almidón se explora para comprender y posiblemente modificar el proceso de malteado de una cebada griega en caso de necesidad. Para abordar el problema, se utilizó una combinación de métodos de inspección por microscopía y por difracción de rayos X para evaluar la variación de la morfología de los gránulos de almidón y el grado de cristalinidad del almidón.
Métodos: Se investigó el efecto del malteado sobre la microestructura del almidón de cebada para un tipo de variedad de cebada griega (Seirios). Las semillas de cebada fueron provistas por ELGO-DEMETER, Instituto de Mejora Vegetal y Recursos Genéticos (Thessaloniki, Grecia). El remojo se realizó a 14 ° C (varios círculos de remojo y aireación) hasta que la cebada alcanzó el contenido de humedad deseado. A continuación, la cebada remojada se dejó germinar a 15 ° C. La germinación fue detenida aplicando una temperatura de secado a 40-45° C durante, por lo menos, 20 h (malta seca). Se obtuvo la malta horneándola durante 6 horas a 100 ° C. La cebada, la malta seca y la malta se molieron para pasar a través de una malla de 0,8 mm antes de analizarse. Para identificar la variación en la morfología de los gránulos de almidón, se utilizaron fotografías de microscopía óptica con tinción con rojo Congo. Además, se obtuvieron los análisis de difracción de rayos X de la harina de cebada, la malta seca y la molienda de la malta. Finalmente, se realizó el análisis de los difractogramas de rayos X para calcular la cristalinidad relativa y el tamaño del cristalito del almidón.
Resultados: Los resultados demostraron variaciones en la morfología de los gránulos de almidón. Las imágenes de microscopía óptica teñida revelaron que los gránulos de almidón en la cebada eran redondos, más grandes, lisos y granulares, y los de la malta seca y de la malta parecían más pequeños y alargados con arañazos en la superficie. Las imágenes teñidas de la microscopía confocal mostraron el comienzo del daño del almidón en la superficie de los gránulos. Los difractogramas de rayos X revelaron que la cristalinidad del almidón de cebada se incrementó durante la producción de malta seca y luego disminuyó durante la cocción, pero aún permaneció mayor que el almidón de la cebada nativa.
Conclusiones: El malteado bajo las condiciones especificadas, afectó la morfología de los gránulos de almidón de la variedad de Seirios, así como la cristalinidad del almidón, lo que sugiere la degradación parcial del almidón durante la maceración y la germinación, así como durante la cocción.

Palabras Clave: cebada, almidón, DRX, microscopía

INTRODUCTION

Starch is composed of amylose and amylopectin packed into granules. There exists a great variation in the granule size distribution among the genotypes (Jaiswal, Båga, Ahuja, Rossnagel, & Chibbar, 2014; Naguleswaran, Vasanthan, Hoover, & Bressler, 2013; Zhu, 2017). Barley starch exists in two types of granules; the large with 10-40μm length and disc-shaped and the small, under 10μm, with irregular spherical shape. Naguleswaran et al. (2013) reported that the weight-based percentages of granules with mean size of 15-16 μm in waxy, normal, and high amylose starches were 88.8, 86.9, and 53.5%, respectively.
According to Chmelík, Krumlová et al. (2001) small starch granules tend to be deeply embedded in the protein matrix of endosperm and gelatinise at higher temperatures and over wider temperature range than large granules. Moreover, the small granules are less susceptible to enzymic degradation during mashing producing hazes that cause technological problems during brewery.
Congo Red (sodium salt of benzidinediazo-biz-1-naphthylamine-4-sulfonic acid) with empirical formula C32H22N6O6S2Na2 and MW 696.66 g/mol is a water-soluble dye which depends on linear hydrogen bonding for staining (Gilbertson, 2018). Congo Red appears to react with the amylose in starch, which is exposed when grains are damaged by structure loss and swollen with water, as when they have been cooked. Both cellulose, and starch grains that have broken bonds, will stain with Congo Red, but their appearance and structure are visibly different, so they can be differentiated under the light as well as confocal microscope. Confocal microscopy is a powerful technique that allows enhanced optical resolution and contrasted images allowing the visualization of morphological structures being very useful for structural carbohydrate analysis (Dürrenberger, Handschin, Conde-Petit, & Escher, 2001).

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According to Bathgate the malted-barley starch had higher apparent amylose content, higher gelatinization temperature, and smaller granules than that from the native barley (Bathgate, 2016). Moreover, the malt amylose has smaller molecular size than that of the barley whereas the amylopectin fractions were of comparable molecular size but differed in the average chain length. The internal chain-lengths of amylopectins are similar, whereas the external chain-lengths are smaller in malted-barley suggesting that the malted barley amylopectin had been degraded by β-amylase to a limited extent (Bathgate, 2016; Chu, Hasjim, Hickey, Fox, & Gilbert, 2014).
Barley starch has A-type polymorph regardless of the granule size (Ao & Jane, 2007; Gao, Vasanthan, & Hoover, 2009; Källman et al., 2015; Kong et al., 2016; Li et al., 2014; Yangcheng, Gong, Zhang, & Jane, 2016) but some genotypes showed a C-type polymorph (Waduge, Hoover, Vasanthan, Gao, & Li, 2006). In the literature the presence of V-type polymorph was also reported and was related to the amylose–lipid inclusion complexes (Gao et al., 2009; Källman et al., 2015).
X-ray diffractometry revealed diversity in the degree of crystallinity of starch granules (Ao & Jane, 2007; Kong et al., 2016; Li et al., 2014). The literature reported that the degree of crystallinity of starches ranged from 10.7% to 44.3% (Källman et al., 2015; Kong et al., 2016; Li et al., 2014; Waduge et al., 2006) with the waxy starch showing highest degree of crystallinity followed by normal and high amylose starches (Naguleswaran et al., 2013).
Barley is widely used cereal for malting. During malting the conversion of native starch into fermentable sugars depends on starch composition, morphology, and molecular and granular structural features (Naguleswaran et al., 2013). Endoamylases, hydrolyse native starch in several steps which consist of diffusion to the solid surface, adsorption and finally catalysis (Oates, 1997). Malted barley starch has higher percentage of amylose and an amylopectin component with degraded external chains (Bathgate, 2016).
Malting of barley induces extensive physical, chemical and structural changes of endosperm (Brennan et al., 1997). The starch granules are released from the protein matrix are gelatinised and became accessible to hydrolytic enzymes during mashing. Thus, it is desirable to know both the variation and development of the structure of barley starch endosperm in order to determine the malting quality of barley. Application of light and confocal microscopy as well as X-ray diffraction analysis will help in the investigation of the surface structure of the starch granules as well as in the structural changes of starch during malting.
The purpose of this study was therefore, the examination the structural changes that occur within the granule interior of starches (molecular structure characterization) from native and malted Greek barley cultivar using light microscopy and confocal microscopy in combination with X-ray diffractometry.

1. METHODS

1.1 Sample and chemicals

Barley kernels of variety Seirios were obtained from the ELGO-DEMETER, Institute of Plant Breeding and Genetic Resources (Thessaloniki, Greece). The barley kernels (with hulls) were free of any impurity. Congo red was acquired from Merck (Darmstadt, Germany). All chemicals used were of analytical grade.

1.2 Malting procedure

Barley kernels (native barley) were thoroughly cleaned by washing with tap water and then soaked in water for 48 h at 14 °C; the soaking water was changed at 8 h intervals. After soaking, the grains were evenly spread on trays and allowed to germinate in dark chamber with 85% moisture content. The temperature of the kernels during germination step was kept at 15 °C. The germination was terminated when the acrospires (sprouts) were grown up to approximately 75% of the grains length by first drying in an air oven at 40 - 45 °C for 28 h (dry malt was obtained at this step) and then at 100 °C for 6 h (malt). The withered rootlets were gently brushed off from the obtained dry malt and malt. The whole barley kernels, the whole dry malt and the malt kernels were milled using a mill (Falling Number AB Type 120 grinder, S-12611, Stockholm, Sweden) equipped with 0.8 mm sieve. The flours were then packaged in polyethylene bag and stored at 4 °C till use.

1.1. Light microscopy microstructure

The microstructure of barley as well as malt flour were examined by light microscopy. The whole barley, dry malt and malt flours were prepared to suspension on a microslide with distilled water, stained with diluted Congo red solution and covered with a coverslip that had been cleared of bubbles. The Congo red was used in order to visualize starch damage and imaged in brightfield. It is recognized that Congo red stains damaged starch granules red but not undamaged starch. Photographs were acquired by light microscopy (LSM 700, Carl Zeiss Micro Imaging GmbH, Jena, Germany) and camera (AxioCam ERc5s). Red staining was viewed under microscope magnification of 200 times.

1.2. Confocal laser scanning microscopy (CLSM)

Flours were stained with Congo red as previously mentioned in section 2.3 and then the dyed samples were left to dry at ambient temperature. In exciting light (excitation wave length, 488 nm) intact starch granules are unstained and appear black.

Contrary, the penetration of the red colour in the starch granules reveals the damage of the starch granules. A confocal laser scanning microscope (LSM 700, Carl Zeiss Micro Imaging GmbH, Jena, Germany) was used to examine the samples. The whole barley flour was used as a control sample.

1.3. X-ray diffraction (XRD) analysis

For the X-ray diffraction measurement of the flours was used an X-Ray Diffractometer X'PertPRO, model MPD, (PANalytical, the Netherlands) that was operated at 45 kV and 40 mA. A divergence slit of 1°, an antiscatter slit of 2° and a receiving slit of 0.4 mm were used. Flours (~200 mg) were placed in the special holders and scanned in the range 6–45° diffraction (2θ) at a scan speed of 0.008°/min with a step size of 0.04°.

1.4. Analysis of X-ray Diffractogram

The computer peak fitting program (origin pro 2015) has been used to determine precisely the peak positions which are characteristic of A- and B-type polymorphs.
The measurement of the crystallinity from the diffractograms, was performed as followed: in the region of interest, a base line was drawn from starting of the curve to the end of the curve as well as at the base of peaks. The relative crystallinity was calculated between 13 and 25° using the formula:
%crystallinity = Acr/(Aam+Acr),
where, Acr and (Aam+Acr) are the measured areas of upper region above peak base line, representing X-ray scattering of the crystalline portion and the whole area under diffractogram comprising both crystalline (Acr) and amorphous portion (Aam).

In addition, the crystallite size was calculated using Scherrer formula:

$$D\ (Å)=0.9\ \lambda/FWHM\times\cos\theta.$$

where, λ is the X-ray wavelength (0.15418 Å), FWHM is the full width of the peak at half maximum in radians and θ is the peak, in radians.
The X-ray pattern of the crystalline portion (13-25°) was analysed with software OriginPro. First were deconvoluted peak profiles and found the respective θ degree of barley, dry malt and malt flour. Then was calculated the total crystallinity as well as the percentage that each peak (15, 17-18, 20 and 23°) contributes to the total crystallinity.

2. RESULTS

2.1. Light microscopy

The Congo red has been used to identify starch since it has a strong interaction with polysaccharides through noncovalent affinity and synthesizing a red complex (Lamb & Loy, 2005). In addition, the Congo red has the ability to stain red the cellulose fibres (Samim, Sandkuijl, Tretyakov, Cisek, & Barzda, 2013). Therefore, both cellulose-like components, and starch granules that have broken bonds, will be stained with Congo Red. They can be easily differentiated under the microscope since their appearance and structure are visibly different.
Starch granules observed in the Figure 1A-C were of two types, both big and small, characteristic for the barley. A decrease in the size of the granules and a change in their shape with malting were observed. The granules became more elongated. The cellulose fibres contained in the flours were stained red and one can distinguish them from the starch granules (Figure 1A–C). In native barley (Figure 1A), it was observed only a few number of starch granules stained red suggesting a low level of damaged/degraded starch. On the other hand, on the surface of the big and small starch granules of the dry malt (Figure 1B) and malt (Figure 1C) were observed fissures and cracks. More fissures and cracks were observed on the surface of the starch granules of malt.

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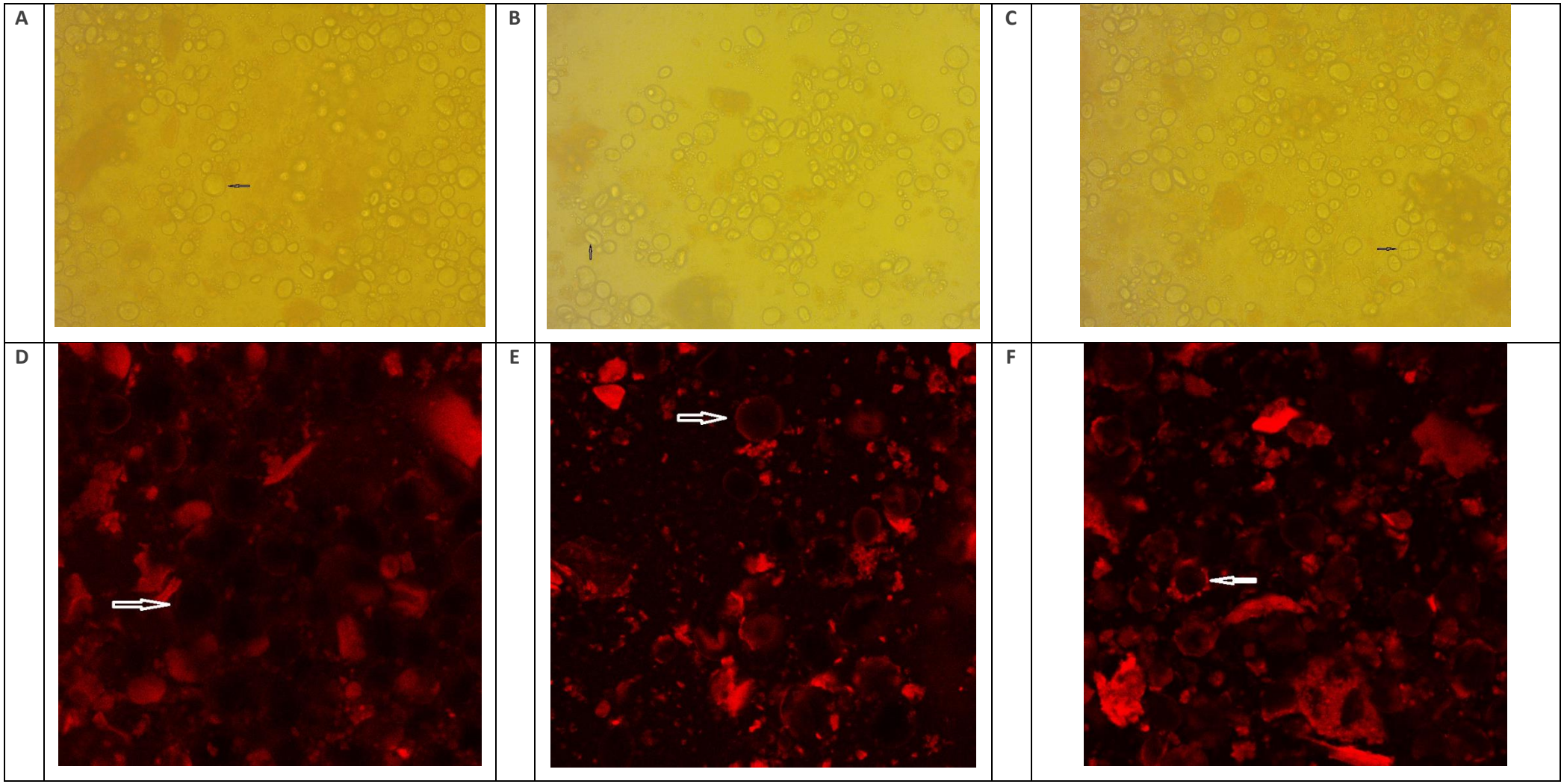

Figure 1. Light (Up) and Confocal (Down) microscopy photographs of Congo red staining : (A, D) whole barley flour (B, E) whole dry malt flour (C, F) whole malt flour

2.2 Confocal microscopy

The confocal photographs of the flours from barley, dry malt and malt are shown in the Figure 1D, E and F, respectively. Stained with red are observed amorphous cellulose-like components of the flour whereas the intact starch granules are visible as black round circles. It is generally known that the damaged starch granules appear red under the confocal microscope. In Figure 1D it is observed that only few granules are coloured red showing the low percentage of damaged starch in the native barley as well as during milling. Contrary, in the dry malt it was observed that the number of intact granules (black circles) was significantly reduced and almost all starch granules showed a thin red aureole. In the malt, the starch granules showed a thicker aureole than that observed in the dry malt. On the other hand, there is not observed any change in the core of the starch granules.

2.3 XRD analysis

The X-ray diffractograms of whole grain flours from barley, and dry malt and malt are presented in Figure 2. As for cereals the malted samples, showed the typical "A" type peak assignments.

Barley, dry malt and malt flours presented similar diffraction patterns with strong peaks at 2θ ≈ 15°, one unresolved doublet at ~17-18°, ~23°, indicating an A-type crystalline pattern (Figure 3 a-c). In addition, the lower peak at 2θ = 20° (Figure 2) was attributed to the formation of a well-formed V-structure which was a consequence of the inserting of bulky group (carboxyl (COOH) and carbonyl (CO)) into starch chains (Pérez & Bertoft, 2010). There were observed no significant changes in the X-ray diffraction patterns between the barley, dry malt and malt.

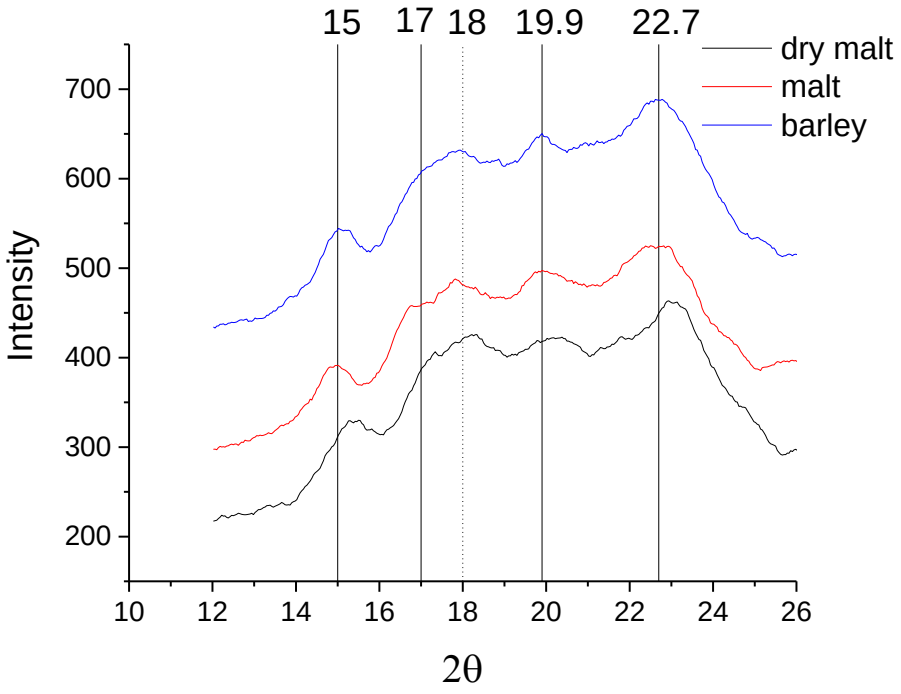

Figure 2. Smoothed XRD patterns for barley, dry malt and malt flours.

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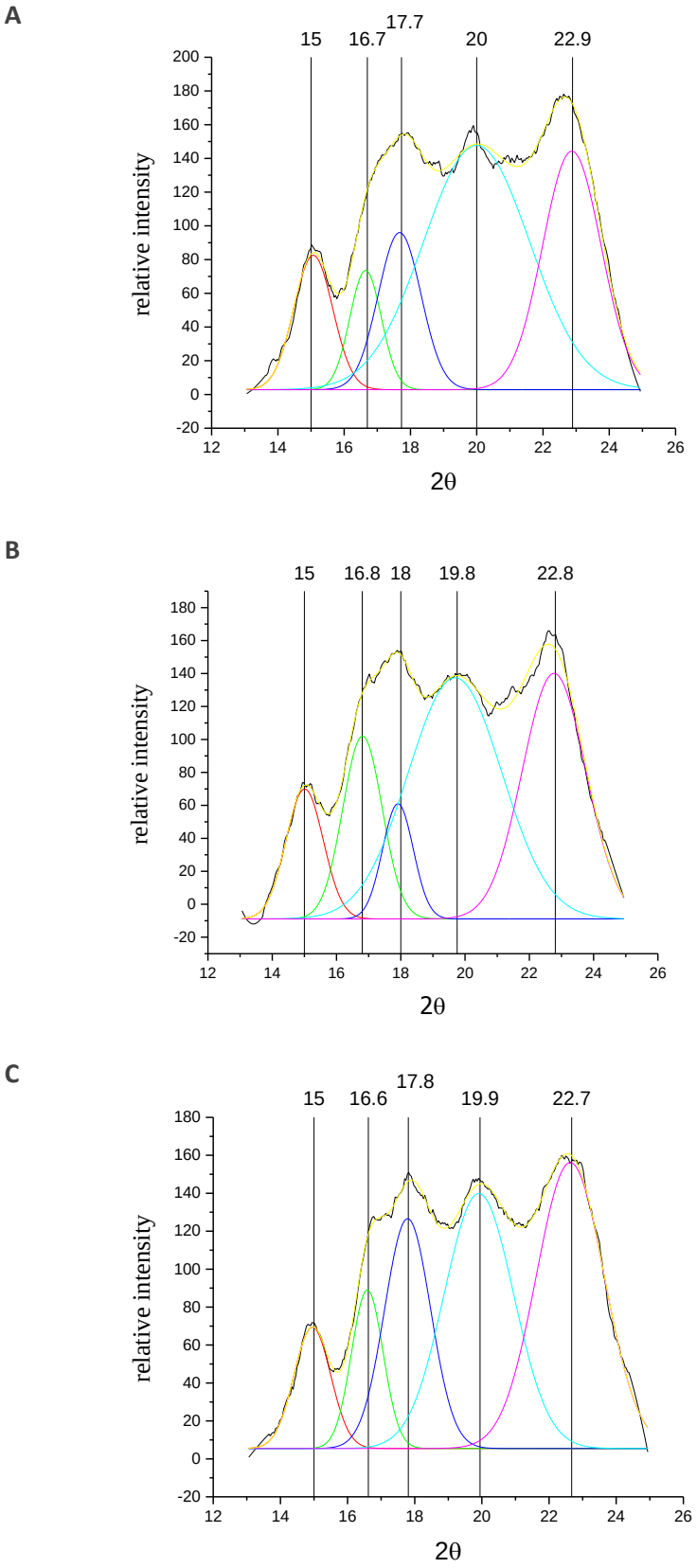

Figure 3. Deconvoluted peak profiles for the X-ray pattern of the crystalline portion of barley flour (A), dry malt (B) and malt (C).

On the other hand, the relative crystallinity varied among the samples (22.7, 24.5, and 22.9% for barley, dry malt, and malt, respectively). It was observed an increase of the overall relative crystallinity value of the dry malt compared to native barley and malt (24.5 vs 22.7 and 22.9%, respectively) (Figure 4).
The increase in the intensity of the peak at 20° during malting is attributed to the formation of a V-type complex favoured when a fatty lipid is grafted into starch chains (Figure 4). The relative crystallinity at the angle 15° is decreased with malting. On the other hand, the crystallinity at 23° was increased in dry malt but decreased in the malt. The opposite was observed for the crystallinity at 17-18°.

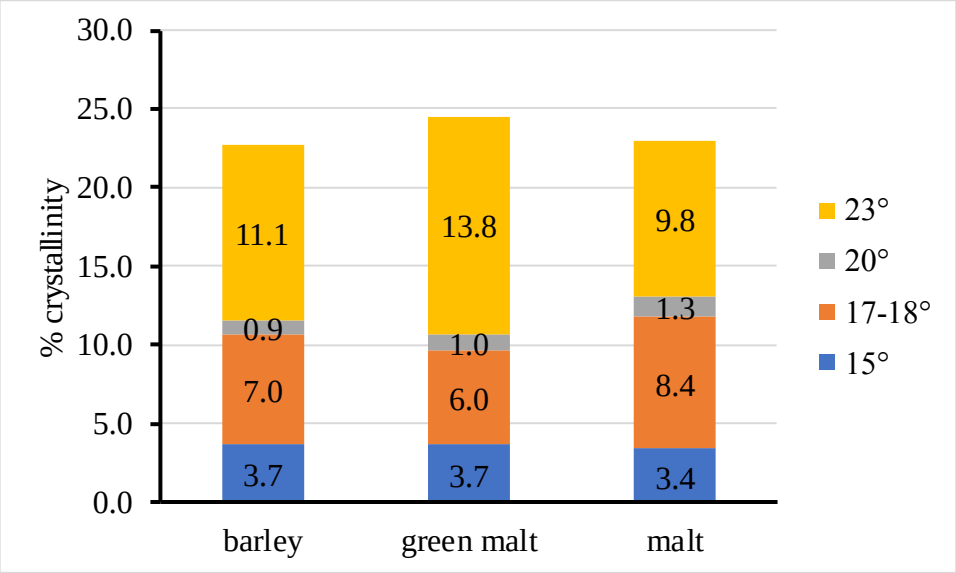

Figure 4. Relative crystallinity of barley, dry malt, and malt flour calculated from the crystalline peaks of the deconvoluted X-ray diffractograms.

Table 1 - Microstructural parameters for barley, dry malt and malt using deconvoluted x-ray data

Sample	2θ	D (nm) deconvoluted
barley	15	8.91
	16.8	10.05
	17.7	6.19
	19.9	16.14
	22.9	4.77
dry malt	14.9	8.02
	16.8	10.05
	17.8	8.05
	19.9	8.97
	22.8	4.51
malt	14.8	8.91
	16.7	11.48
	17.7	6.71
	19.9	11.53
	22.8	5.07

The average sizes of crystallites in the crystalline regions (peaks) of barley, dry malt and malted barley starch are calculated by Scherrer equation (Table 1). The D values observed on different peaks ranging from 4.77 to 16.14 Å for barley, from 4.51 to 10.05 Å for dry malt and from 5.07 to 11.53 Å for malt indicate the variation in the crystallinity of starch during malting. For the

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barley, dry malt and malt, the smallest crystallite size of the starch is 4.77Å, 4.51Å and 5.07Å observed at 22.9°. It was observed that malting leads to changes in crystallite size - it decreases at the angle 20° from 16.14 in barley to 8.97 in dry malt and then increases to 11.53 in malt.

3. DISCUSSION

Distribution of starch granular size observed in the Greek barley is a bimodal distribution of large and small granules, referred to as A- and B-granules, respectively being in accordance with the reported data in the literature (MacGregor & Ballance, 1980). The morphology of these starch granules changed during malting process, both A and B granules become slightly smaller and more elongated (Figure 1A-C). This is in accordance with the data reported in the literature (Greenwood & Thomson, 1959). These changes in the size and shape are possibly due to the decrease of the moisture content (reduced degree of swelling) as well as to the enzyme attack. On the other hand, the creation of the fissures and cracks on the surface of the starch granule suggests that enzymes produced during germination step attack the surface of the starch granules without being inserted inside the granule. The increased number of scratches during kilning suggest that enzymes attack the granules even after first drying. These cracks will represent the location of initial enzyme attack during wort preparation where enzymes will have direct access to the granule interior. In the literature is reported that amylases affect the starch granules in two ways; exocorrosion and endocorrosion (Oates, 1997; Sujka & Jamroz, 2007). During the exocorrosion the erosion of the entire granule surface or sections of it happens resulting in fissures and pits. On the other hand, during endocorrosion hydrolysis of the channels from selected points on the surface toward the granule centre takes place resulting in granule fragmentation. It seems that during malting there was observed only exocorrosion. Possibly the enzymic degradation of the surface of the starch granules happened in the presence of high moisture during steeping and germination. Enzymes begin to hydrolyse the starch chains attacking mainly amylopectin responsible for the amorphous region (Colonna, Buléon, & Lemarié, 1988) during steeping process to a certain straight-chain length, and then the new free chains can be ordered during drying (dry malt) forming double helix and increasing crystallinity (from 24.5 to 22.7%). In the literature it was reported that hydrated starches are known to give well-defined peaks since the added moisture permits the already longitudinal molecules present in the amorphous regions to organize into crystalline units (Singh, Ali, Somashekar, & Mukherjee, 2006). Thus, partial destruction of the amorphous region of starch following by a subsequent alignment of crystallites may be responsible for the observed increase in the crystallinity.
The increase observed in the crystallinity at the angle 20° could be related with the swelling of starch granules during steeping that in their turn may increase the possibility for the lipids (mainly fatty acid and monoglycerides) present in the flour matrix to be inserted into the amylose chain released. Moreover, the fatty lipids present in the flour may be inserted to some of the linear broken chains during enzymic attack. The non-alignment of these chains may be responsible for the observed decrease in the crystallite size at angle 20° during dry malt production. The increase of the crystallinity at angle 20° from dry malt to malt may be due to enhanced ordering of lipid molecules that were present as V-amylose–lipid complexes within granules of the native starches. This suggestion is in agreement with the increase (from 8.97 to 11.53 Å) in the crystallite size of the V-amylose–lipid complexes.
The degree of crystallinity is reported to be one of the several factors that determine starch digestibility (Benmoussa, Suhendra, Aboubacar, & Hamaker, 2006) whereas channels present in the starch granules are the main route of enzyme penetration and the central cavity area represents the starting point of enzyme digestion.

CONCLUSIONS

Malting affected the starch granule morphology as well its crystallinity. The endogenous enzymes seemed to hydrolyse the external surface of starch granules during production of dry malt as well as during kilning producing fissures and cracks. These fissures and cracks will facilitate the introduction of enzymes within the starch granule and fast hydrolyzation during mashing process. During production of the dry malt there was increased crystallinity of starch whereas during kilning (in malt) the crystallinity was decreased. On the other hand, there was observed and increase in the crystallite size in certain crystalline regions and a decrease in others. However, the mean crystallite size in the crystalline region at 20°, first decrease and then increase but were always smaller than that in the native barley.

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COMPORTAMENTO ELASTO-PLÁSTICO AO CORTE DE ESTRUTURAS FAVO-DE-MEL E AUXÉTICAS REFORÇADAS

ELASTO-PLASTIC SHEAR BEHAVIOR OF REINFORCED HONEYCOMB AND AUXETIC REENTRANT LATTICES

COMPORTAMIENTO ELASTO-PLÁSTICO AL CIZALLADURA DE ESTRUCTURAS PANAL Y AUGÉTICAS REFORZADAS

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RESUMO

Introdução: Materiais auxéticos possuem um coeficiente de Poisson negativo. Ainda que a existência de auxéticos isotrópicos seja teoricamente possível, estes são inexistentes em estados naturais. Assim, tem havido um esforço para produzir auxéticos artificiais principalmente pelo design de favos de mel invertidos (reentrantes).
Objetivos: Este estudo explora novas estruturas reforçadas em favo de mel e auxéticas para melhorar o comportamento elasto-plástico estrutural em deformação de corte.
Métodos: A análise de elementos finitos (FEA) é usada para simular a carga de corte em estruturas reforçadas em favo de mel e auxéticas reentrantes, enquanto as tensões e deformações impostas são monitorizadas.
Resultados: A transformação auxética promove um aumento no módulo de corte, no entanto, gera deformações plásticas a valores mais baixos de deformação. No entanto, o efeito de fechamento de materiais auxéticos tende a reduzir a área de plasticidade afetada.
Conclusões: Neste estudo, é apresentada uma nova geração de estruturas reforçadas em favo de mel e auxética reentrante. Ainda que a transformação auxética gere deformação plástica para menores deformações de corte, é capaz de reduzir as áreas afetadas pela plasticidade e elevar a rigidez de corte.

Palavras-chave: Favo-de-mel; Auxético; Corte; Elastoplástico; Análise por elementos finitos.

ABSTRACT

Introduction: Auxetic materials possess a negative Poisson's ratio. Even though, the existence of isotropic auxetics is theoretically possible, they seem to be absent in natural states thus, there has been an effort to produce artificial auxetics mostly by the design of inverted (reentrant) honeycombs.
Objetives: This study explores a novel Reinforced Honeycomb Lattices and Auxetic Reentrant lattices to enhance structural elasto-plastic behaviour in shear deformation.
Methods: Finite element analysis (FEA) is used to simulate shear loading in Reinforced Honeycomb and Auxetic Reentrant lattices, while the imposed stress and strains are monitored.
Results: Auxetic transformation promotes an increase in shear modulus, however, it generates plastic strains at lower values of shear deformation. However, the closing effect of auxetic materials, tends to reduce the plastic affected area.
Conclusions: In this study, a novel generation of Reinforced Honeycomb and Auxetic Reentrant Lattices are presented. Even though, the auxetic transformation generates plastic strain for lower shear deformation regimes, it is able to reduce the areas affected by plasticity and elevate shear stiffness.

Keywords: Honeycomb; Auxetic; Shear; Elasto-Plastic; Finite element analysis.

RESUMEN

Introducción: Los materiales augéticos poseen un coeficiente de Poisson negativo. Aunque la existencia de augétios isotrópicos es teóricamente posible, parecen estar ausentes en los estados naturales, por lo tanto, se ha realizado un esfuerzo para producir augéticos artificiales principalmente mediante el diseño de panales invertidos.
Objetivos: Este estudio explora un enrejado de nido de abeja reforzado y enrejado reentrantes para mejorar el comportamiento estructural elasto-plástico en la deformación al cizalladura.
Métodos: Análisis de elementos finitos (FEA) se utiliza para simular la carga de cizallamiento en rejillas nido de abeja reforzadas y Reentrant augéticas, mientras que el estrés impuesto y las cepas se controlan.
Resultados: La transformación augética promueve un aumento en el módulo de cizalladura y genera deformaciones plásticas a valores más bajos de deformación por cizalladura. Sin embargo, el efecto de cierre de los materiales augéticos tiende a reducir el área plástica afectada.
Conclusiones: En este estudio, se presenta una nueva generación de enrejado de nido de abeja reforzado y rejillas augética reentrante. Apesar de que la transformación augética genera deformación plástica para regímenes de deformación de cizallamiento más bajo, es capaz de reducir las áreas afectadas por la plasticidad y elevar la rigidez a la cizalladura.

Palavras-clave: Nido de abeja; Augéticos; Cizalladura; Elasto-Plástica; Análisis de elementos finitos.

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1. INTRODUCTION

Auxetic materials are characterized by an expansion or contraction in the transverse direction while they are axially tensioned or compressed, therefore, they possess a negative Poisson's ratio (Carneiro *et al*, 2013). While most common linear elastic isotropic materials tend to change their shape and have an isochoric deformation behavior, the referred materials are expected to keep their shape while experiencing extreme volume changes (Alderson & Alderson, 2007). Although this kind of deformation behavior may seem counterintuitive, it is supported by the thermodynamic balance of the classical Theory of Elasticity, which states that the Poisson's ratio has a lower limit of -1 and an upper limit of 0.5 and 1, respectively, for three-dimensional (Fung, 1965) and two-dimensional (Jasiuk & Chen, 1994) approaches.

Even though, the existence of isotropic auxetics is theoretically possible, they seem to be absent in natural states, being mostly found in anisotropic forms (e.g. (Voigt, 1882) (Gatt *et al*, 2015) (Keskar, 1992)). Thus, since the mid-1980's there has been an effort to produce artificial auxetics, first by the design of reticulated macrostructures (Almgren, 1985) and, later, by the manufacturing of the auxetic foams (Lakes, 1987). Since then, there were developed macrostructural models that show auxetic behavior (see for e.g. the reviews of (Carneiro *et al*, 2013) and (Greaves *et al*, 2011)), being the most common obtained by the inversion of lateral ribs of honeycombs to obtain two-dimensional reentrant structures and, on a three-dimensional approach, inverted tetrakaidecahedrons (Lakes, 1987).

It is expected that this kind of materials show enhanced specific mechanical properties such as high damping (Lim *et al*, 2013), higher hardness (Hu & Deng, 2015) and superior shear resistance (Greaves *et al*, 2011). However, in absolute terms given the cellular configuration that are used to produce these structures, their mechanical behavior may be compromised for many practical structural applications.

This study shows the transformation of Reinforced Honeycomb Lattices and some considerations for their transformations in Reinforced Auxetic Reentrant Lattices. Furthermore, their elasto-plastic behavior is characterized in terms of in-plane shear deformation to determine the advantage of the production of these lattices in their auxetic configuration.

2. METHODS

Regular honeycombs are characterized by a hexagonal configuration where all ribs have the same length. In order to transform this kind of structures into auxetic reentrant structures, the fundamental geometry must be changed, usually, to an arrangement where the horizontal ribs (H) have a superior dimension than the vertical ribs (L), generally using the proportion of H=2L (Figure 1 – a).

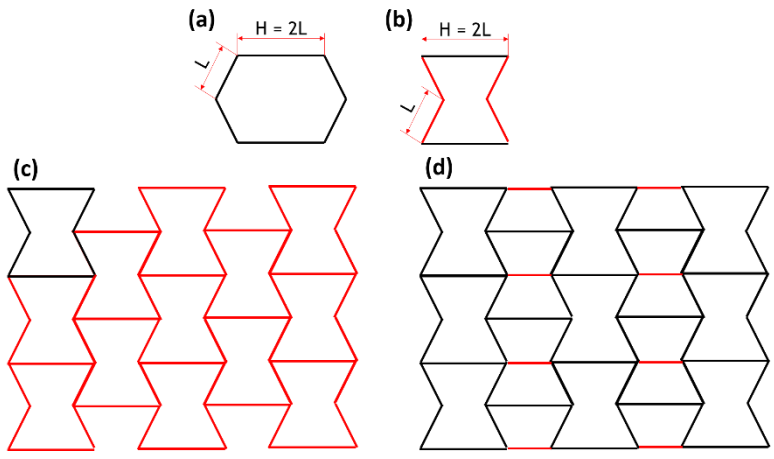

Figure 1. General procedure to model Reinforced Auxetic Reentrant Lattices:
a) original Honeycomb; b) Rib inversion; c) Cell assembly; d) Adding of reinforcement struts.

By the inversion of the vertical ribs (Figure 1 – b), it is possible to transform the defined Honeycomb into an Auxetic Reentrant geometry. By the assembly of these geometries (Figure 1 – c), a lattice configuration may be obtained. Finally, Reinforced Auxetic Reentrant Lattices are proposed by this study and may be achieved by the addition of horizontal struts in every other row of unitary cells (Figure 1 – d).

A similar procedure may be applied to the Honeycomb (Figure 2 – a), by eliminating the rib inversion step and proceed directly to the assembly phase (Figure 2 – b). The Reinforced Honeycombs Lattices that are proposed by this study, may be obtained by the assembly of horizontal struts in the manner that was referred in the previous procedure (Figure 2 – c).

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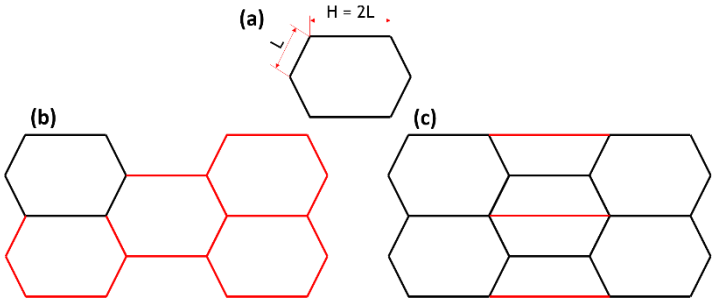

Figure 2. General procedure to model Reinforced Honeycomb Lattices:
a) Initial Honeycomb; b) Cell assembly; c) Adding of reinforcement struts.

Using the both procedures for Reinforced Reentrant Auxetic and Honeycomb Lattices, there were obtained the two-dimensional structures shown in Figures 3. The overall dimensions of the design structures are presented in Table 1.

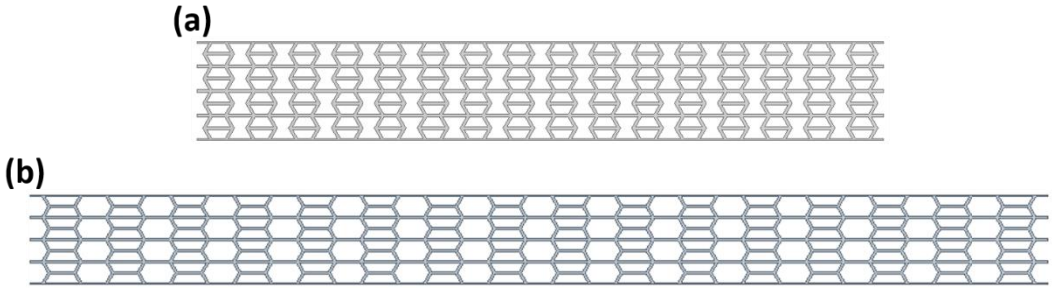

Figure 3. Novel reinforced structure: a) auxetic reentrant and b) honeycomb.

Table 1 – General dimensions of the modeled lattices.

Unitary Cells	Distance Dimensions [mm]	H – Horizontal Ribs	40
		L – Vertical Ribs	20
		B – Rib Thickness	4
	Angular Dimensions [°]	Auxetic Reentrant	30
		Honeycomb	120
Final Lattices	Height [mm]	138	
	Length [mm]	Auxetic Reentrant	960
		Honeycomb	1600

The elasto-plastic behavior of the modeled structures when subjected to a shear effort were estimated by use of FE analysis, recurring to a static structural routine of ANSYS 17. Fundamentally, the defined models were fixed in their lower face, while their upper face is subjected to a Displacement of 5 [mm] in the horizontal direction (XX axis), being these boundary conditions represented in Figure 4. In terms of Apparent Shear Strain (γ), the applied displacement corresponds to 0.035, enough to characterize the local deformations within the plastic regime without entering in severe plastic deformation. This corresponds to a simulation of these structures in practical situations where small permanent dislocations are allowed within their life span.

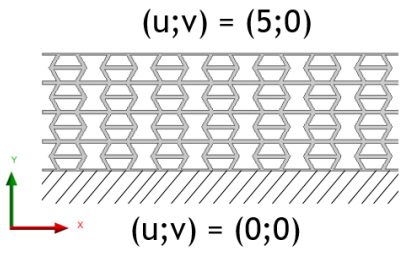

Figure 4. Representation of boundary conditions used in the FE analysis.

To characterize these elastic, local plastic and the corresponding transition regime, an Aluminum with a Bilinear Isotropic Hardening behavior was selected as the base material for the FE routines. The input conditions for the numerical procedures are shown in Table 2, being that the main outputs of the simulation are the correspondent Reaction Forces and Local Plastic Strain values and locations. The fundamental material properties were determined from previous tensile tests (Fig. 5 – a). Details of the mesh may be observed in Fig.5-b, where the elements (Table 2) are smoothly discretized to obtain smooth simulation results.

Table 2 - FEA input conditions.

Material	Aluminum (Bilinear Isotropic Hardening)	Young's Modulus [GPa]	71
		Poisson's Ratio [-]	0.33
		Yield Strength [MPa]	230
		Tangent Modulus [GPa]	0.5
Contacts	Type	Frictionless	
	Formulation	Pure Penalty	
Mesh	Element Type	SHELL181 – 1 [mm] element size	
	Description	Rectangular - 4 Noded	
Boundary Conditions	Upper Face	{u=5;v=0} [mm]	
	Lower Face	{u=0;v=0} [mm]	
Solver	Sparse direct equation solver		

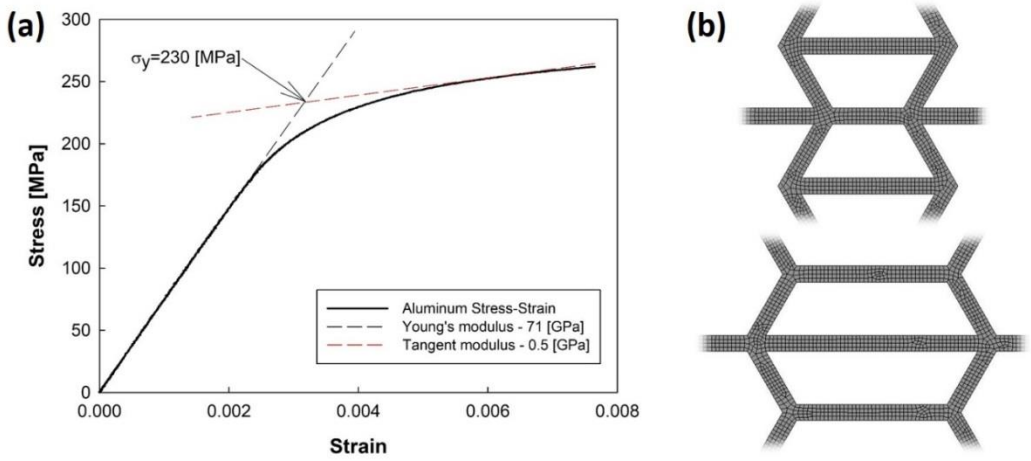

Figure 5. a) aluminum tensile behavior; b) meshing details.

3. RESULTS AND DISCUSSION

The Reaction Forces and Displacements from the numerical results are presented in Figure 6, by the calculation of the instant values of Apparent Shear Stress (τ) and Strain (γ).

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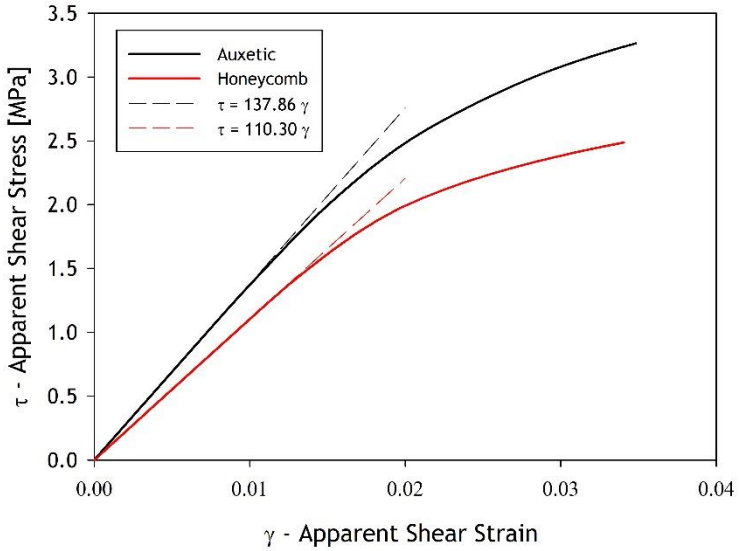

Figure 6. Resultant Apparent Shear Stress-Strain curves.

The dashed lines in Figure 6 are linear regressions that follow the slope of the linear elastic domain of the simulated models. Fundamentally, these values of slope represent the Apparent Shear Modulus (G*), and it maybe concluded that the transformation of the Reinforced Honeycombs Lattices to a Reinforced Auxetic Reentrant configuration, generates an elevation in this constant.

Comparing the results with theories (Fig.7) that describe the elastic behavior of cellular structures (e.g. honeycombs), it is shown that the reinforcement are able to generate an increase in shear stiffness. Reinforced Honeycombs display a substantial increase in Apparent Shear Modulus relatively to the theories of Gibson (1982) and Meraghni (1999). This implies that rib flexing does not completely dominate the deformation mechanism and the rib thickness influences the overall mechanical response in shear. This is further proved by the proximity of the results with the thick honeycomb theory described by Malek (2015). Additionally, it is shown that the transformation into Reinforced Auxetics is able to further elevate the shear stiffness.

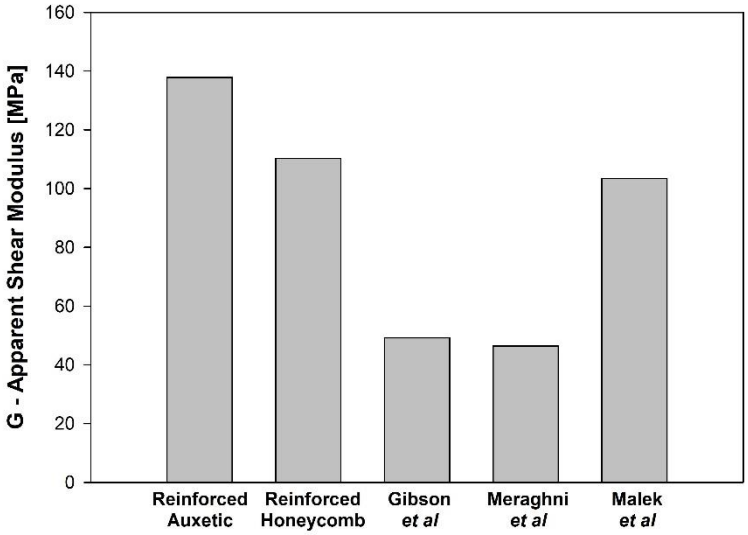

Figure 7. Comparison of the results with honeycomb elastic theories.

Even though, the elastic behavior of these structures due to their cellular morphology do not follow the behavior of the classical Theory of Elasticity, a parallel may be found to justify this increase of this elastic constant. Given that the Shear

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Modulus (G) of an elastic isotropic solid is related to the Young's Modulus and Poisson's ratio by Equation 1 (Timoshenko & Goodier, 1951), it is expected that this constant increases for low values of Poisson's ratio as plotted in Figure 8.

$$G = \frac{E}{2(1+\nu)} \qquad (1)$$

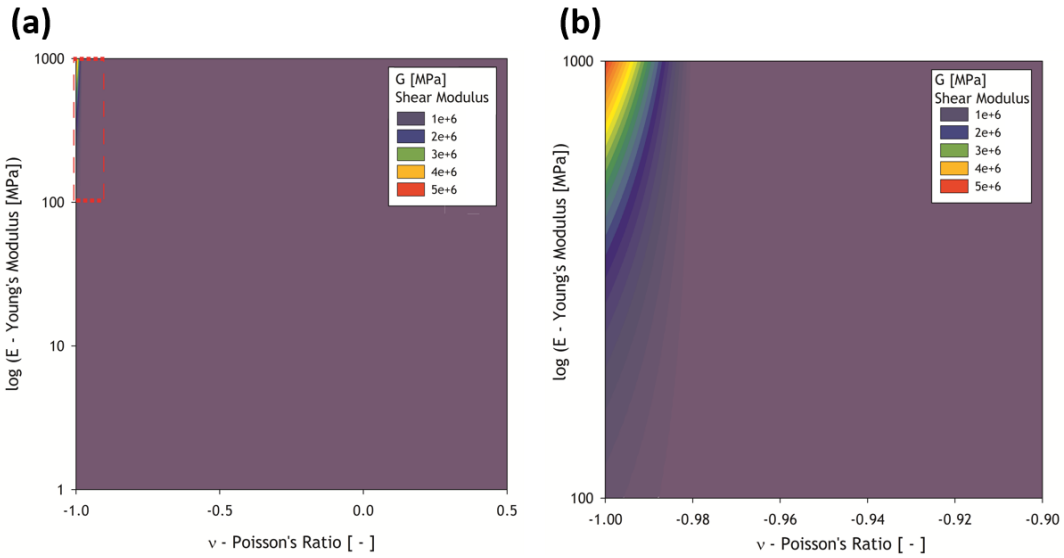

Figure 8. Linear elastic isotropic Shear Modulus as a function of the Young's Modulus and Poisson's ratio.

By the normalization of the Shear Modulus to the Young's modulus (G/E) (represented in Figure 9) it may be further observed that a general decrease in the Poisson's ratio will generate an increase in the Normalized Shear Modulus. Thus, these theory is able to predict an expected increase in this elastic constant as shown by the numerical results.

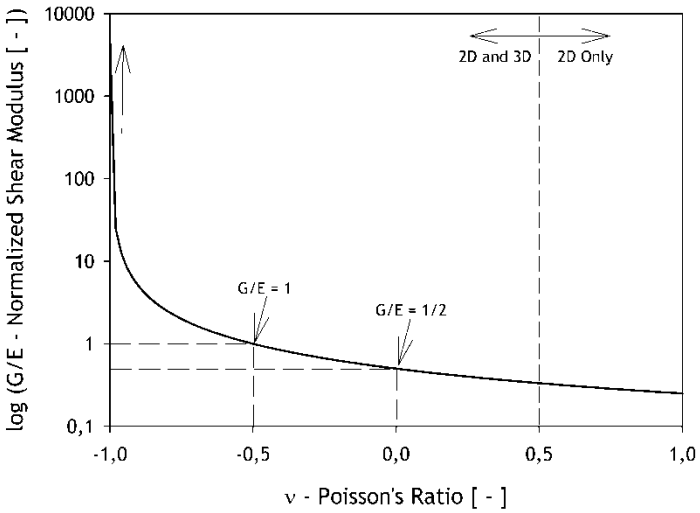

Figure 9. Normalized Shear Modulus (G/E) as a function of Poisson's ratio.

Further increasing the Apparent Shear Strain, the curves in Figure 6 tend to deviate from the linear regression, meaning that plastic deformation occurs and the overall deformation of the lattices is ruled by an elasto-plastic regime. Figure 10 shows the instant values of Maximum Normal Plastic Strain (ε^P) resultant from the numerical results, where it may be observed that Plastic Strain is verified at lower Apparent Shear Strain in Reinforced Auxetic Reentrant Lattices and even the elevation rate of Plastic Strain is more elevated.

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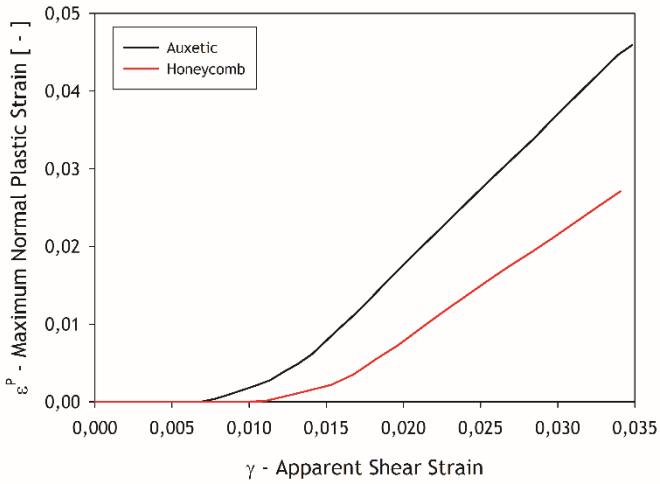

Figure 10. Maximum Normal Plastic Strain as a function of Apparent Shear Strain.

This progression in the increase of Maximum Normal Plastic Strain is further detailed in Figures 11 and 12, where several stages of Apparent Shear Strain are portrayed. From these figures it is verified that stress concentration generates Plastic Strain in the vertical ribs at lower Apparent Shear Strain for Reinforced Auxetic Reentrant Lattices (Figure 11). However, observing Figure 12, it may be stated that the Affected Plastic Area tends to be wider in the Reinforced Honeycomb Lattices and form Plastic Hinges in the horizontal ribs at lower Apparent Shear Strain. This last fact is suggested to contribute to the lowering of Apparent Shear Stress in Reinforced Honeycomb Lattices show in Figure 6, and thus contributing for the lower performance of these structures when subjected to shear loading.

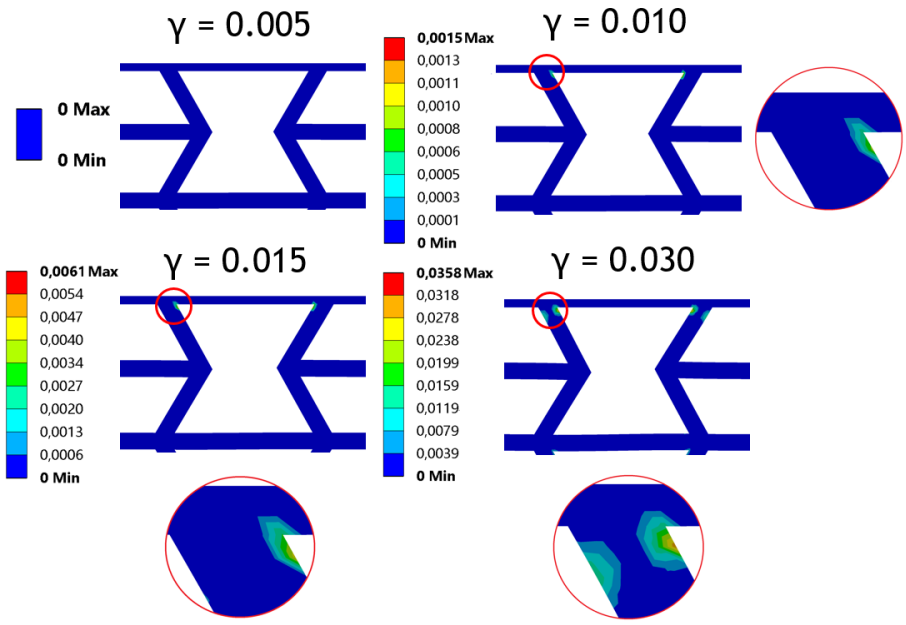

Figure 11. Detail progression of Plastic Strain in Reinforced Auxetic Reentrant Lattices.

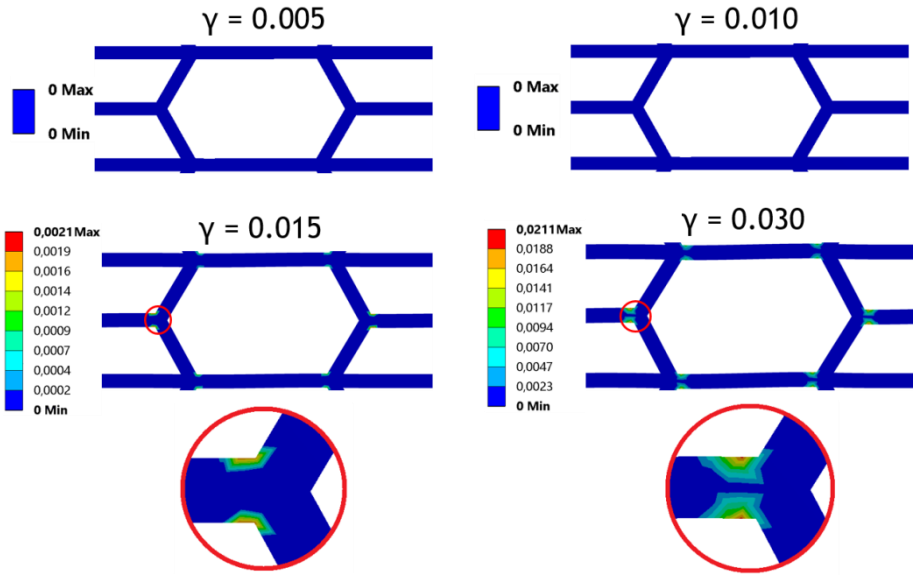

Figure 12. Detail progression of Plastic Strain in Reinforced Honeycomb Lattices.

CONCLUSIONS

In this study, a novel generation of Reinforced Honeycomb and Auxetic Reentrant Lattices are presented, while their elasto-plastic behavior due to shear loading is explored. Considering the overall results and discussion of the performed work, the following conclusions were drawn:

(i) Apparent Shear Modulus is higher in Reinforced Auxetic Reentrant Lattices than in Reinforced Honeycomb Lattices with the same cell dimensions;

(ii) Plastic Strain is verified at lower Apparent Shear Strain for Reinforced Auxetic Reentrant Lattices;

iii) Local Maximum Plastic Strain is higher in Reinforced Auxetic Reentrant Lattices, however, Reinforced Honeycomb Lattices display a wider Plastic Affected Zone;

iv) Development of Plastic Hinges occurs at lower Apparent Shear Strain for Reinforced Honeycomb Lattices, and overall this effect diminishes their performance in shear loading when compared with Reinforced Auxetic Reentrant Lattices.

ACKNOWLEDGEMENTS

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APLICAÇÂO WEB PARA ANÁLISE DE TESTES DE AVALIAÇÃO
WEB APPLICATION FOR THE ANALYSIS OF ASSESSMENT TESTS
APLICACIÓN WEB PARA ANÁLISIS DE PRUEBAS DE EVALUACIÓN

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RESUMO

Introdução: Um teste de aferição permite a avaliação de uma dada competência ou capacidade de um individuo. Estes testes são importantes quer no âmbito de instituições de ensino, quer no âmbito empresarial para o recrutamento de recursos humanos.
Objetivos: O artigo tem como principal objectivo apresentar a aplicação web designada "Evaluate" para a análise de testes de aferição.
Métodos: Descreve-se o desenho e implementação da aplicação que permite fazer a gestão de questões ou itens de aferição, a partir dos quais é possível a construção de testes de avaliação. A partir dos resultados dos alunos na resolução desses testes, são calculadas as principais estatísticas descritivas usadas na análise de testes de aferição das aprendizagens ao abrigo da teoria clássica dos testes. A aplicação "Evaluate" foi desenvolvida em Python usando a *framework* Django e foi testada com provas de aferição reais.
Resultados: Para cada teste são atribuídas cotações aos itens e, a partir das respostas dos alunos, são obtidas diversas estatísticas tais como: índice de dificuldade e de discriminação, correlação ponto-bisserial, coeficiente de consistência interna do teste. A aplicação permitir ainda a análise gráfica do desempenho dos alunos por cada item e no teste como um todo.
Conclusões: A aplicação "Evaluate" é uma ferramenta que contribui para um melhor conhecimento dos instrumentos de aferição usados na avaliação de conhecimentos, permitindo identificar inconsistências e consequentemente introduzir melhorias no processo.

Palavras-chave: Teoria clássica dos testes; Avaliação electrónica; Análise de dados.

ABSTRACT

Introduction: An assessment test enables the evaluation of an individual's competence or ability. Such tests are important for both teaching and professional training institutions, as well as for the recruiting of human resources in the enterprise.
Objectives: The present paper introduces the "Evaluate" web application, for the analysis of assessment tests.
Methods: The design and implementation of the application is described, which allows the management of assessment items, used to constitute evaluation tests, upon which results the main descriptive statistic values used under the classical test theory in the analysis of assessment tests are calculated. The application was developed in Python, within the Django framework, and tested with real assessment tests.
Results: Scores are assigned to each assessment item, and various statistics — such as difficulty and discrimination index, point-biserial correlation, test internal consistency coefficient — can be obtained upon the answers of the subjects, as well as a graphic analysis of the performance of each subject on each assessment item, as well as on the test as a whole.
Conclusions: The "Evaluate" application makes a meaningful contribution to a better knowledge of assessment tools used in competence evaluation, by allowing the detection of inconsistencies and the consequent improvement in the process.

Keywords: Classical test theory; E-assessment; Data analysis

RESUMEN

Introducción: Una prueba de evaluación permite la evaluación de una determinada competencia de un individuo. Estas pruebas son importantes tanto en el ámbito de las instituciones de enseñanza, tanto en el ámbito empresarial para la contratación de recursos humanos.
Objetivo: El artículo tiene como principal objetivo presentar la aplicación web designada "Evaluate" para análisis de pruebas de evaluación.
Métodos: Se describe el diseño e implementación de la aplicación que permite hacer la gestión de cuestiones, a partir de los cuales es posible la construcción de pruebas de evaluación. A partir de los resultados de los alumnos en la resolución de estas pruebas, son calculadas las principales estadísticas descriptivas utilizadas en el análisis de pruebas de evaluación de los aprendizajes bajo la teoría clásica de las pruebas. La aplicación "Evaluate" fue desarrollada en Python usando el *framework* Django y fue probada con pruebas de evaluación real.
Resultados: Para cada prueba se asignan cotizaciones a los ítems y, a partir de las respuestas de los alumnos, se obtienen diversas estadísticas por cada ítem e por cada prueba. La aplicación permite además el análisis gráfico del desempeño de los alumnos por cada ítem y en la prueba como un todo.
Conclusiones: La aplicación "Evaluate" es una herramienta que contribuye a un mejor conocimiento de los instrumentos de medición usados en la evaluación de conocimientos, permitiendo identificar inconsistencias y consecuentemente introducir mejoras en el proceso.

Palabras clave: Teoría clásica de las pruebas; evaluación electrónica; análisis de datos

INTRODUCTION

Assessment or evaluation tests are an essential instrument in all teaching and learning processes, namely within the scope of formative assessment with e-assessment platforms. By their use, we can compare the targeted objectives with the results achieved along the joint work of teachers and students, which enables the adjustment of strategies and the improvement of work methodologies.

Furthermore, assessment and evaluation in higher education related literature demonstrates that the students generally exhibit a positive attitude towards the adoption of e-assessment, and that there is a strong correlation between the results achieved with paper and pencil traditional tests, with those obtained with e-assessment, where most questions are of the closed answer type (Ferrão, 2010). This evidence incentive the adoption of e-assessment practices in other contexts. The field of work known as Computerized adaptive testing (CAT) is defined by the International Association for Computerized Adaptive Testing (CAT)[1] aiming at "the redesign of psychological and educational measuring instruments for delivery by interactive computers". CAT can be used for tests of ability or achievement and for measures of personality and attitudinal variables. Its objective is to select, for each examinee, the set of test questions from a pre-calibrated item bank that simultaneously most effectively and efficiently measures that person on the trait". Considering that in the digital world, any conceptual assessment framework faces two main challenges: (a) the complexity of knowledge, capacities and skills to be assessed; (b) the increasing usability of computer and web-based assessments, which requires innovative approaches to the development, delivery and scoring of tests, Ferrão and Prata (2014; 2015) explore the adoption of computerized adaptive testing (CAT), aiming at reducing the test size, and simultaneously controlling the impact of such reduction upon the measurement error, in other words, at the production of tests so structured as to generate results which reflect faithfully the degree of knowledge acquisition of the students. In Costa & Ferrão (2015) the authors conceptually present three essential modules of a CAT platform — Informatics (procedures related to test delivery and data collection), Statistical methods (procedures related to data modelling, scoring and calibration) and Topic contents (Items bank and procedures related to items bank manager) — upon which the Adaptive Test Developer operates. There are two statistical approaches to the analysis of the tests, both as a whole, as well as on a question/item basis: the classical test theory (CTT) and the item response theory (IRT) (Hambleton, Swaminathan, & Rogers, 1991). For the purpose of this paper the methods chosen are in accordance with the classical test theory (CTT) (Lord & Novick, 1968).

The present paper[2] introduces the "Evaluate", a web application which provides its users — docents and other professionals involved in assessment processes — with a statistical analysis of the tests. The application belongs to the aforementioned Informatics and Statistical methods modules, and it permits the management of students, questions and assessment tests. Upon input of each student's evaluation grid, a parameter analysis can be performed, either on a question by question basis or on the entire test as a whole.

The paper is structured as follows: both the CTT foundations and the parameters that can be computed with the current version of "Evaluate" are referred in section 2; some related works are referred in section 3; a brief description of the requirements analysis, the proposed architecture, the data model and some representative use cases illustrate the application design in section 4; the "Evaluate" implementation and results obtained with sample questions and tests are presented in section 5 and section 6 presents the conclusions and possible courses of action in future research.

1. CLASSICAL TEST THEORY

The definition of measurement is "a procedure for the assignment of numbers (scores, measurements) to specified properties of experimental units, in such a way as to characterize and preserve specified relationships in the behavioural domain" (Lord & Novick, 1968) (p.17). A relevant statistical approach used in educational measurement is the CTT. According to such approach, it is assumed that variable $X^{(T)}$ represents the student's learning. The observable variable X is generally obtained by test administration. If the tests were instruments with absolute precision, the observed value X, regardless of the test used, would be equal to true value $X^{(T)}$. In a hypothetical situation where the student is repeatedly tested **T** times, the formula (1) $X = X^{(T)} + \varepsilon_t$, (t = 1, ..., T), represents the relationship between the true and the observed values. In that formula, ε represents the measurement error, which is assumed to be non-systematic, homoscedastic, and non-correlated with the true value (Guilford & Fruchter, 1978).

The application "Evaluate" comprises an item bank, i.e. a set of questions or assessment items, thus allowing the user to build a test meeting some specifications. For each test, the correction criterion is inserted, that is, the number of points for each item and the value assigned to the corresponding response for each student. The student's score on the test is computed. Based on these data, several descriptive statistics are computed for the purpose of studying the properties of the test and its items, as for

[1] http://iacat.org/

[2] A Portuguese version of this paper was published in the proceedings of the International Conference on Engineering - A vision for the Future, ICEUBI 2017, Covilhã, Portugal, December, 2017.

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example the average, standard deviation, and variance of the students' scores. The histogram of the standardised scores can be drawn. Finally, the internal consistency of the test is calculated using the Cronbach alpha coefficient.

Considering the student j, their score on the test is computed by applying the formula (2) $x_j = \sum_{i=1}^{n} perc_{ij} * c_i$, where **n** is the number of items that compose a test, $\mathbf{perc_{ij}}$ is the score in percentage obtained by each student j (=1, 2, …, m) on item i (=1, 2, …, n), and $\mathbf{c_i}$ is the number of points assigned to that item i.

The average of the scores is given by formula (3) $\bar{x} = 1/m * \sum_{j=1}^{m} x_j$, and the standard deviation is given by formula (4) $s = \sqrt{\frac{1}{m-1} * \sum_{j=1}^{m}(x_j - \bar{x})^2}$ where, **m**, $\mathbf{x_j}$, and $\bar{x}$ are defined above. The variance of X is given by formula (5) $var(x) = s^2$ where **s** is the standard deviation of the variable X.

The alpha Cronbach coefficient (Guilford & Fruchter, 1978) is used to quantify the internal consistency of a test, a statistic based on the correlation between the different items in the same test, which expresses the degree of test consistency across all responses for all items. The alpha Cronbach takes values between 0 and 1, where 0 represents the total absence of test consistency and 1 indicates that the test is 100% consistent. This coefficient is calculated by equation (6): $\alpha = \frac{n}{n-1} * \left(1 - \frac{\sum_{i=1}^{n} {s_i}^2}{s^2}\right)$ where ${s_i}^2$ is the variance of item i. The smaller the variance across items, the more α - Cronbach approaches the value 1, that is, the more consistent the test will be. From among the several existing tables used to categorize the internal consistency of a test according to Cronbach's alpha coefficient, the one shown in table 1 (Vieira, 2015) was adopted.

The items characteristics are quantified through the discrimination and difficulty indexes. The discrimination index measures the capacity of the item to distinguish the high performance group of students from the low performance group of students, and its values vary from −1 to 1. The difficulty index is provided by the proportion of correct answers to item **i** (Guilford & Fruchter, 1978). Therefore, high values indicate easy questions. Generalising the definition of the difficulty index to non-dichotomous items, the level of difficulty of a question is given by the average of the classification obtained by the set of students on this question (Guilford & Fruchter, 1978), and is calculated with equation (7): $Difficulty_i = \frac{\sum_{j=1}^{m} mark_j}{m}$, where **m** corresponds to the total number of students who answered the item and $\mathbf{mark_j}$ represents the mark that each student obtained in item **i**. It should be noted that in a dichotomous model, in which the score is either right or wrong (1 or 0), the difficulty of a particular item in one test is given by the percentage of students who, in the said test, got the item right. To categorize the difficulty of an item, the classification presented in table 1, taken from (Ramsay, 2018), was followed.

Table 1 - Classification of the test internal consistency according to the Cronbach's Alpha, item difficulty designation and discrimination index designation.

Cronbach's Alpha	**Test internal consistency**
α >= 0.9	Excellent
0.9 > α >= 0.8	Good
0.8 > α >= 0.7	Acceptable
0.7 > α >= 0.6	Questionable
0.6 > α >= 0.5	Poor
< 0.5	Unacceptable
Item difficulty	**Item difficulty designation**
0 - 20%	Very difficult
21 - 60%	Difficult
61 – 90%	Moderately difficult
91 – 100%	Easy
Point-biserial correlation	**Discrimination index designation**
Between 0 and 0.3 (0 and -0.3)	Very bad
Between 0.3 and 0.5 (-0,3 and -0.5)	Bad
Between 0.5 and 0.7 (-0.5 and -0.7)	Moderate
Between 0.7 and 0.9 (-0.7 and -0.9)	Strong
> 0.9 or < -0.9	Very Strong

There are numerous approaches to the calculation of the discrimination degree, which can be divided into two main types: i) the use of criterion groups and ii) the correlation of the item with the total of the items. We adopted one approach of each type. The D index uses criterion groups, i.e., it calculates the difference of the scores between a higher group (for example the 27% better tests) and a lower group (the 27% worse tests) (Guilford & Fruchter, 1978). This percentage of 27% is a commonly used value for the size of the two groups, which can be changed in accordance with the user's preference. The D index is calculated with the formula (8) $\sum_{j=1}^{m'} x_j - \sum_{j=1}^{m'} t_j$ where **m'** is the number of students in the criterion group (e.g. if the test is answered by 100 students and the criterion group size is 30%, **m**' is equal to 30); $\mathbf{x}_j$ corresponds to the grade obtained in the item by the student j (= 1,2, ... m') belonging to the upper group (that is, of the best grades); t_j corresponds to the grade obtained in the item by the student j (= 1,2, ... m') belonging to the lower group. The higher the D index, the more discriminating that item is. A zero or negative D index indicates that the item is non-discriminatory.
Within the correlation type approaches, "Evaluate" adopts the point-biserial correlation, which also provides a measure for the degree of discrimination (Guilford & Fruchter, 1978), by quantifying the correlation between the values obtained for any given item and the total test scores. In order to apply this coefficient to non-dichotomous variables, a correct value which defines the minimum percentage required to consider an answer as correct, is associated with the test, though changeable by the user. The point-biserial correlation is given by equation (9): $rpb = \frac{\bar{xa}-\bar{xt}}{s}\sqrt{p/q}$ where **xa** is the mean of the students' score who answered the item correctly, **xt** is the total mean of the test, **s** is the standard deviation of the test, **p** is the proportion of students who scored on the item, and **q** (= 1-p) is the proportion of students who did not answer the item correctly. The item discrimination given by the point-biserial correlation is classified according to table 1 Ratner, 2018).

2. RELATED WORK

The development of learning assessment platforms has received the attention of research teams all over the world, especially in countries where large scale assessment is current practice. For instance, TAO™ (Testing Assisté par Ordinateur) (TAO, 2018) is one of the best known since the OECD adopted it for PISA (Programme for International Student Assessment). According to (Kirsch & Lennon, 2017) the PIAAC (Programme for the International Assessment of Adult Competencies) "marks an inflection point in the evolution of large-scale comparative assessments" because it is the first fully computer-delivered survey, involving a multistage adaptive testing and the development of an open-source platform. Another well known platform is Concerto (Concerto, 2018) which enables the creation of online adaptive tests using the IRM approach. The platform Moodle is also currently used in the context of learning analytics research. For example, Strang (2016) imported data from Moodle to SPSS statistical package in order to conduct data analyses on students' performance. The Strang' study is focused on the predictive power of learning analytics data and its relationship with student performance. The author applied similar descriptive and correlational statistics as those used by the Evaluate application.

3. APPLICATION ANALYSIS AND DESIGN

This section presents the analysis and design of the Evaluate application, namely a summary of the requirements analysis, application architecture, as well as adopted technologies and data model. By way of illustration, two use cases are briefly described: how to create a test and how to retrieve information about tests, students or questions.

3.1 Requirements Analysis for Evaluate

The "Evaluate" application has the following functional requirements:

- Add, edit and remove questions, tests, students and users available in a database;
- Upload and process of assessment grids;
- Statistical analysis of any given test (mean, standard deviation, Cronbach's Alfa);
- Graphical display of the values obtained in the test analysis;
- Statistical analysis of any given question, providing graphical representation;
- Database search for tests, questions and students;
- Creation of tests accessible to any user.
- Restriction of test access privileges to one single user.

The non-functional requirements are the following:

- The application is to be accessible from any browser, multi-user, and independent of the user's technological expertise;
- Whenever the test values are changed all statistical information about the test and questions must be recalculated;
- User access credentials are available as an option, whenever test access privileges are required.

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3.2 Architecture and Data Model

"Evaluate" has a three-tier client/server architecture: the presentation tier is implemented in HTML and CSS, the logic tier is implemented in python and the data tier uses a SQLite database. The Django framework was used as development environment (Django, 2014; 2018).

The application data model, shown in figure 1, contains as main entities users, tests questions and students. The database table *User* stores the access credentials of each user. Table *Test* stores the data for each test such as creation date, subject and which user creates it; should the creator field be NULL, the test is public. The table *TestSettings*, associated to table *Test*, stores the values of *correctvalue* and *percentage* for a given test. The attribute *correctvalue* represents the score above which the answer is considered correct. The attribute *percentage* represents the value for the parameters of the higher/lower intervals for the criterion groups used to calculate the discrimination *D* index. For a given test, different values of these two attributes can be defined to study their impact in the computed statistics. The database table *Question* stores the text and type of the questions. One question may belong to several tests and the type of the question depends on the kind of answer sought (open answer, multiple choice, etc.). The table *QuestionType* stores the possible question types. The table *QuestionItem* links table *Question* with table *Test,* and contains the score assigned to each question in a given test (attribute *item_pontuation*).

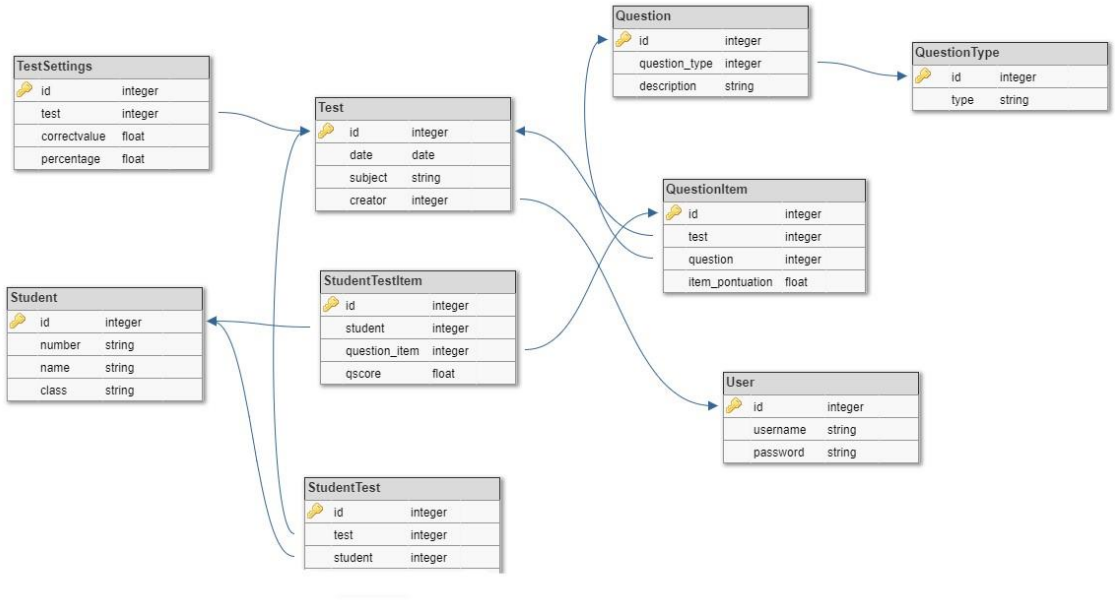

Figure 1. Data model

Finally, the table *Student* stores student data such as number, name and course in which the student is enrolled. The table *StudentTest* represents the many-to-many relationship between the entities *Student* and *Test:* a student may be submitted to several tests and a test may be applied to several students. Table *StudentTestItem* enables the association between a student (table *Student*) and a test question stored in table *QuestionItem*.

3.3 Use cases

When creating a new test, the user may choose to login with their identity credentials or not. In the first case only the user will have access to the test data; in the latter, the test will be public.

After selecting "NewTest", the user will be asked to input the initial test data, namely the date and subject. Next, the user has three options to proceed:

1. "Manually" - To manually enter the test questions, the question score, the students who have answered the questions in the test and the score obtained by each student in each question;
2. "Upload Grid" - To *upload* a CSV file, containing the test evaluation grid. The header of this file has two rows, the first one contains the question identifier and the second the question score. Each question will so be described in one column, from the second column onwards. The first column is reserved for the student identification header. In the data section, each row presents the data for one student. The student identification will be in the first column and their score for each question on the respective question column.

3. "Upload Index" – To upload a CSV file, named index, which contains the evaluation grid for the situation in which all questions are dichotomous, that is, they are marked as correct or incorrect (1 or 0). The structure of that file is as follows: the first row has the score assigned to each question; in the remaining rows the first column has a sequential line number, the second column has the number of students who answered according to the following pattern. For example, in a test with four questions, the line "34 231110", means that the answer pattern number 34 corresponds to 23 students and these students got right the first, second and third questions and got wrong the fourth question.

After the test creation is completed, the user may check the data correction in the webpage "Test Detail" that exhibits all test data.

To check all information regarding tests, questions and students, the user can access any of the options: "Test", "Student" and "Question". For each option, all elements, namely tests, students or questions, can be selected, or alternatively any particular element may be selected from that list. The user may choose to use a search bar to look for given values of any available parameters, to select a particular element or group of elements from each list.

4. IMPLEMENTATION

This section introduces the results that can be obtained with the "Evaluate" application in terms of tests and items analysis. To check the application functionalities, some assessment tests from several subjects and several teachers were used. The curricular unit of Object Oriented Programming (POO), taught in the Computer Science degree, was used to illustrate the Evaluate application. After students solved the test, a teacher corrected them creating an assessment grid that is inserted in the application as shown in figure 2. Eighteen students were submitted to the test, named "test 53", which contains 17 questions and was assigned a 12 points scored (see figure 3).

Test number 53

created by

Date: July 12, 2017

Subject: POO

Test Options

Test Settings | Delete Test

Students | Questions | Test Variables | Test Charts | Test Grid

Num de aluno	53poo.csv:0.75	53poo.csv:0.5	53poo.csv:0.75	53poo.csv:0.25	53poo.csv:0.75	53poo.csv:0.5	53poo.csv:0.5	53poo.csv:1.0	53poo.csv:0.25	53poo.csv:1.0	53poo.csv:0.5	53poo.csv:1.25	53poo.csv:0.75	53poo.csv:0.5	53poo.csv:1.25	53poo.csv:0.75	53poo.csv:0.75
a1	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	0.00%	100.00%	100.00%	90.00%	80.00%	20.00%	86.67%	70.00%	40.00%	26.67%	10.00%
a2	66.67%	60.00%	0.00%	100.00%	0.00%	0.00%	100.00%	40.00%	100.00%	90.00%	80.00%	60.00%	33.33%	0.00%	40.00%	26.67%	20.00%
a3	100.00%	100.00%	100.00%	100.00%	86.67%	100.00%	80.00%	25.00%	100.00%	75.00%	80.00%	40.00%	100.00%	100.00%	0.00%	0.00%	0.00%
a4	66.67%	60.00%	100.00%	100.00%	100.00%	100.00%	80.00%	100.00%	100.00%	60.00%	40.00%	60.00%	100.00%	100.00%	80.00%	33.33%	15.00%
a5	100.00%	80.00%	0.00%	100.00%	93.33%	100.00%	80.00%	100.00%	100.00%	100.00%	40.00%	32.00%	40.00%	80.00%	0.00%	0.00%	0.00%
a6	53.33%	60.00%	80.00%	100.00%	100.00%	100.00%	0.00%	90.00%	100.00%	80.00%	80.00%	40.00%	100.00%	70.00%	60.00%	26.67%	0.00%
a7	40.00%	50.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	20.00%	16.00%	0.00%	0.00%	20.00%	0.00%	0.00%
a8	40.00%	0.00%	0.00%	100.00%	66.67%	0.00%	60.00%	20.00%	100.00%	0.00%	60.00%	16.00%	26.67%	0.00%	0.00%	0.00%	0.00%
a9	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	90.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	80.00%	0.00%
a10	46.67%	80.00%	33.33%	100.00%	100.00%	0.00%	0.00%	65.00%	100.00%	0.00%	50.00%	0.00%	20.00%	70.00%	0.00%	33.33%	0.00%
a11	46.67%	0.00%	33.33%	100.00%	0.00%	100.00%	0.00%	10.00%	0.00%	0.00%	50.00%	0.00%	40.00%	20.00%	0.00%	0.00%	0.00%
a12	46.67%	80.00%	86.67%	100.00%	80.00%	0.00%	80.00%	65.00%	100.00%	0.00%	30.00%	0.00%	40.00%	0.00%	0.00%	33.33%	0.00%
a13	73.33%	0.00%	46.67%	100.00%	80.00%	0.00%	60.00%	100.00%	100.00%	0.00%	40.00%	16.00%	86.67%	70.00%	0.00%	0.00%	0.00%
a14	33.33%	40.00%	0.00%	80.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	60.00%	0.00%	0.00%	60.00%	0.00%	0.00%	0.00%
a15	80.00%	80.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	80.00%	40.00%	100.00%	0.00%	0.00%	0.00%	0.00%
a16	86.67%	100.00%	0.00%	100.00%	33.33%	0.00%	50.00%	90.00%	0.00%	50.00%	70.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
a17	26.67%	80.00%	0.00%	80.00%	53.33%	70.00%	0.00%	40.00%	100.00%	65.00%	80.00%	16.00%	100.00%	80.00%	0.00%	0.00%	0.00%
a18	66.67%	30.00%	80.00%	100.00%	86.67%	100.00%	40.00%	90.00%	100.00%	0.00%	20.00%	0.00%	26.67%	0.00%	0.00%	0.00%	0.00%

Figure 2. Evaluation grid for test number 53

As can be seen in figure 2, the grid contains in the first row the question identifier and in the second row the assigned question score. The following rows contain, for each student, the score, in percentage, obtained in each question. Access to the option "Test Setting" is given in the upper right corner. In this option the user can redefine the values of the *correctvalue* and *percentage* variables, as introduced in section 4.2. *Correctvalue* is the value above which the answer is considered correct, defaulting to 100%; the *percentage* variable is the value of the interval for the criterion groups, and it defaults to 27%.

Figure 3 presents on the left the list of students that answered the test 53. By selecting a student in that list, that student's assessment results can be retrieved. The questions list of test 53 can be seen on the right side of figure 3. The details of each question can be accessed by selecting the associated link in this list.

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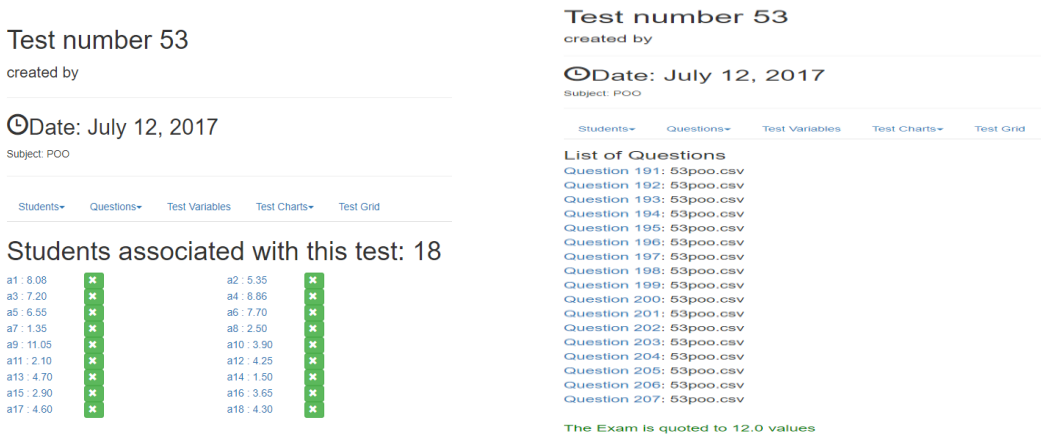

Figure 3. Details of test 53 and its list of questions

4.1 Test Analysis

The statistical analysis of the test can be obtained by selecting the "Test variables" option that will display the values of mean, standard deviation and Cronbach's Alpha coefficient calculated according to the scores obtained by the students in the test. The values obtained with test 53 can be seen on the left hand side of figure 4, and are namely: mean = 5.03; standard deviation = 2.63; Cronbach's Alpha = 0.99. The formula used in the computation of each of these values can be visualised by clicking on the green "!" icon.

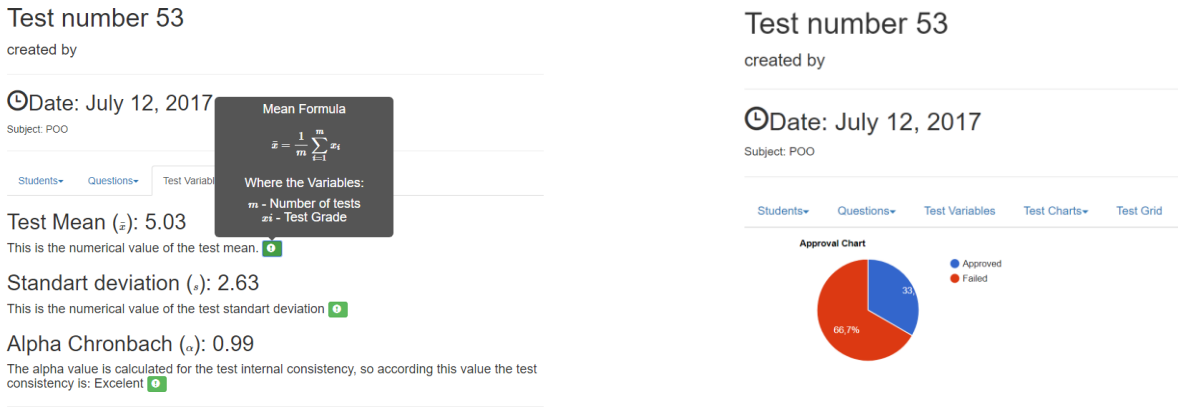

Figure 4. Test variables and approval chart of test 53

Finally, by choosing the option "Test Charts" the graphical representation of the test results can be accessed. The graphic that represents the approved and failed percentages of the students subjected to test 53 is to be found on the right hand side of figure 4. The graphic on the left side of figure 5 shows the histogram of the standardised score values (e.g. Guilford & Fruchter, 1978). It is also possible to build a graphic showing the difficulty level of each test question. Figure 5 on the right shows that most test 53 questions were difficult.

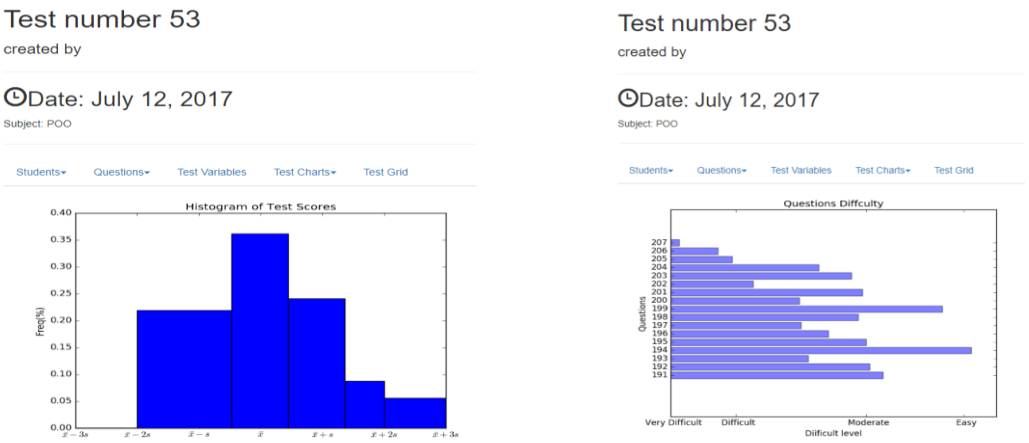

Figure 5. Histogram of test 53 scores and difficulty level of its questions

4.2 Items Analysis

By accessing any given question, and selecting the option "Question variables", the user is granted access to the detailed analysis of any given item, namely to the difficulty level and the discrimination index, the latter calculated by both the point-biserial correlation and the D index. Figure 6 displays the results obtained for question 191, test 53, which, as can be observed, exhibits moderate degrees of both difficulty and discrimination.

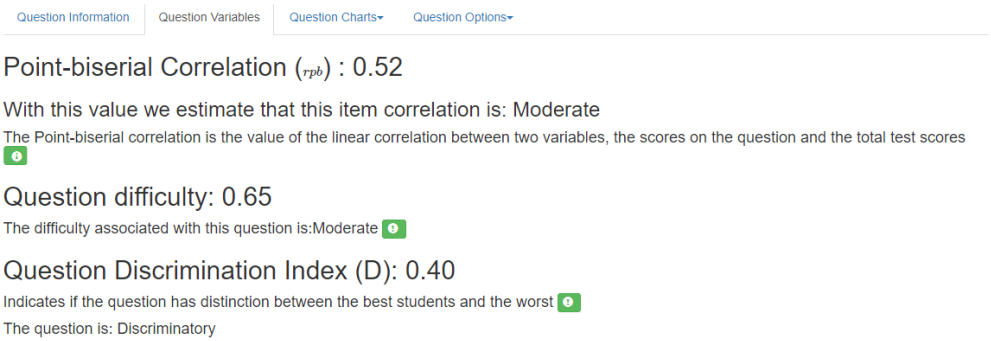

Figure 6. Variables of question 191, test 53

A graphical analysis for each test item is also provided, which displays separately the respective approval and failure rates in a pie chart, and a histogram of the obtained scores. Figure 7 shows the approval chart and score histogram for question 191, test 53.

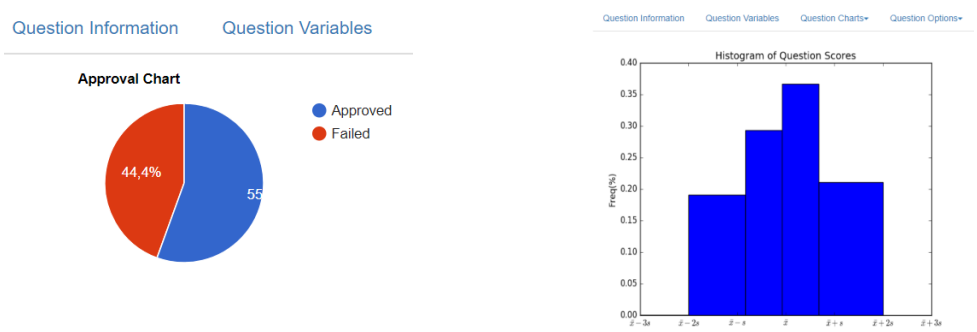

Figure 7. Approval chart for question 191, test 53 and respective scores histogram

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4.3 Discussion

After a first test analysis, the score of each question can be adjusted in order to reach different goals. If the user concludes that the test is too difficult or too easy, a sensitivity analysis can be conducted in order to change each item score and verify in real time the effects of that change. Thus, for each change, the effects in the percentage of approved students, in the test consistency and in the difficulty and discrimination levels of the items can be observed. If some questions reveals as non-discriminating, the user can choose to remove them from the test. If the test has poor or questionable consistency, the point-biserial correlation can be used to identify items that cause most inconsistencies and try to minimize the problem changing the scores assigned to those items. Any change in the scores of an evaluation grid will be reflected in the statistical values calculated to the items, to the test and in the generated graphics. The application "Evaluate" has shown to be a powerful tool to real time analysis of tests results, allowing adjusting and improving the assessment process.

CONCLUSIONS

The application "Evaluate" introduced in this paper implements the main descriptive statistics values used in the analysis of learning processes, in conformity with the CTT model. With "Evaluate", teachers and trainers can easily and intuitively analyse the assessment tests and respective items, as resolved by the examinees; they can identify problems and inconsistencies and on the basis of these improve the evaluation process. This study is part of a wider project that proposes itself to explore complementarity between CTT and IRM, when building an adaptive testing platform. Following the simulation study presented in Ferrão & Prata (2014), we plan to extend the Evaluate application to accommodate IRM. In addition, more work is needed in order to understand the relationship between the item exposure rates, item usage and item bank requirements. Further work also comprises the study of item leverage on overall scores and on the test length reduction.

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ACCESIBILIDAD, PATRIMONIO Y PROYECTO. RE-ARCHITECTURES PARA TODOS

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RESUMO

Introdução: Projectar para proporcionar ao Património Cultural novos ciclos de vida requere que este seja dotado de novas funcionalidades, que seja capaz de assegurar conforto e segurança, e que também seja melhorado e facilitado o seu uso por parte de todos os seus utentes. Esta última questão da acessibilidade é entendida actualmente como uma condição básica de carácter transversal que deve estar presente no processo de projecto do início ao fim.
Objetivos: No ensino da Arquitectura as questões ligadas à acessibilidade são geralmente tratadas como matérias colaterais, ou como um assunto acessório; contudo se se considerarem como um verdadeiro tema projectual, talvez se obtenha um maior compromisso e engajamento por parte dos futuros profissionais.
Métodos: Análise do *estado da arte* a partir de vários estudos publicados e dos problemas relacionados com a sua aplicação. Serão também analisadas as experiências dos estudantes na sua aprendizagem académica. Neste sentido trabalhou-se com base na intervenção nas ruínas do Mosteiro de San Antón em Castrogeriz, situadas no caminho de Santiago.
Resultados: Quando a acessibilidade é tida em conta desde o princípio do projecto, como um mais um requisito, obtém-se melhores soluções arquitectónicas.
Conclusões: Aprofundar a aprendizagem das problemáticas do uso ao alcance de toda a população do nosso Património Cultural permite abordar um dos ingredientes mais significativos da arquitectura: a sua percepção sensorial. As reflexões à volta dos trabalhos em Castrogeriz permitem extrair algumas ideias capazes de contribuir para o debate disciplinar acerca da acessibilidade.

Palavras-chave: Acessibilidade; Património Cultural; Projecto Arquitectónico; Aprendizagem; Percepção sensorial.

ABSTRACT

Introduction: Designing to bring new cycles of life to Cultural Heritage requires providing it with new functionalities, making it appealing and safe, and also improving its conditions of use for all individuals. The third issue, accessibility, currently has to be a basic, cross-sectional requisite incorporated in the project process from beginning to end.
Objetives: In Architectural schools, the matter of accessibility is usually treated as a collateral issue or as a secondary subject. However, if it is considered to be an authentic project substance, future professions will probably be more committed to it.
Methods: Analysis of the *state of the issue* based on various published studies and of the problem areas involved in applying it. The students' experiences in their training were also analyzed, based on their work on the ruins of the San Antón Monastery in Castrogeriz, on the *Camino de Santiago* [The Way of St. James].
Results: When accessibility is considered from the beginning of a project, as just another requisite, better architectonic solutions are achieved.
Conclusions: Focusing on learning about the problem areas involved in the use of Cultural Heritage by all people makes it possible to dig deeper into one of the most significant ingredients in architecture: sensory perception. Reflecting about the work in Castrogeriz can be a source of ideas that contribute to the architectonic debate on accessibility.

Keywords: Accessibility; Cultural Heritage; Architectural Project; Learning; Sensory perception.

RESUMEN

Introducción: Proyectar para poner al Patrimonio Cultural en nuevos ciclos de vida requiere que sea dotado de nuevas funcionalidades, conseguir confort y seguridad, y también mejorar las condiciones de su uso por parte de todas las personas. En nuestros tiempos esta última cuestión, la accesibilidad, debe de ser un requisito básico de carácter transversal que tiene que estar presente en el proceso del proyecto desde el principio hasta el fin.
Objetivos: En la enseñanza de Arquitectura las cuestiones de accesibilidad se suelen tratar como temas colaterales, o como materias auxiliares; sin embargo si se consideran como auténtica sustancia proyectual probablemente se consiga un mayor compromiso de los futuros profesionales.
Métodos: Análisis del *estado de la cuestión* a partir de varios estudios publicados y de las problemáticas de su aplicación. También se analizaron las experiencias de los estudiantes en su aprendizaje. En este sentido se trabajó en la intervención en la ruinas del monasterio de San Antón en Castrogeriz, en el Camino de Santiago.
Resultados: Cuando la accesibilidad se considera desde el principio del proyecto, como un requisito más, se obtienen mejores soluciones arquitectónicas.
Conclusiones: Profundizar en el aprendizaje de las problemáticas del uso por todas las personas de nuestro Patrimonio Cultural permite ahondar en uno de los ingredientes más sustanciales de la arquitectura: su percepción sensorial. Desde las reflexiones alrededor de los trabajos en Castrogeriz se pueden extraer algunas ideas que contribuyan al debate arquitectónico sobre la accesibilidad.

Palabras Clave: Accesibilidad; Patrimonio Cultural; Proyecto Arquitectónico; Aprendizaje; Percepción sensorial.

INTRODUCTION

Traditional architectonic concepts like recovery, reuse, regeneration, or even repair, have become surpassed by a new contemporary attitude: reactivate obsolete architectures and prepare them for a new cycle of life. Among such structures are the buildings, or parts of them, that have survived past life stages, as well as infrastructures and even landscape. Needed are new design perspectives, with a good dose of creative and reinventive capacity, proposals for appropriate uses, and work incorporating sufficient liberty and respect for what has been inherited. Within this sphere of reflection lies, by its own nature, actions on cultural heritage.

A powerful, modern requisite is embedded in this architectonic panorama: providing accessibility. Our building, cities, and landscape have to allow the best use and enjoyment for the greatest number of individuals. Since the end of the 80s in the 20th century, the idea of *Universal Design*, or *Design for Everyone*, has gradually become ever more extended. This universal approach, led by Ron L. Mace, an American architect and designer who was a wheelchair rider, has been sinking in little by little. The objective of this movement is to attain products and environments usable by all people without having to resort to costly adaptations or specialized designs, or specific solutions for concrete groups, to benefit any single individual no matter their age or level of ability, whether physical or intellectual (Mace, 1990).

1. DISABILITY AND ACCESSIBILITY.

When we architects design, we have to recognize that we generally do so thinking about mainstream individuals. We normally think about people similar to ourselves, with all their capabilities available, in both physical and mental terms. This opinion is less than substantiated by even a glance at an environment wider than the usual. We immediately find that there are many people who find it hard to carry out activities in the spaces we build, and we tend to think, *Well, the difficulties arise because they have a disability due to physical, mental, or emotional problems*.

Traditionally, *disability* has been understood from a medical point of view, given that it was considered an endogenous condition of the individual, whether permanent or temporary. This viewpoint has gradually changed to a wider vision that includes the social context and the environment in which our actions are performed. It now tends to be defined as "the expression of a functional, cognitive, or emotional limitation in a social context" (Puga, 2004, p. 21). From this perspective work on architectonic projects needs to try to provide a setting in which individuals with disability can "continue to be *normal*, to continue carrying out the activities needed for the development of a *normal* life" (Puga, 2004, p. 25). If the conditions that generate disability are found in the setting, due to difficult access for some individuals, then we have to improve the venue to make it easier.

In this framework we can understand the appearance of the term *accessibility*. The Royal Spanish Academy Dictionary defines it as: the quality of being accessible. And accessible means: having access; being easily accessed or treated; easily comprehended, understandable. In the sense that interests us, accessibility can be defined as the quality of easy access to the surroundings and to the spaces so that any person --even those with a disability-- can reach a place, an object, or a service.

Accepting the existence of this problem to approach and solve its consequences involves an even greater advantage. If the functional demands of settings could be reduced, this would mean an improvement for anyone with a limitation and also for the rest of the population: everyone would benefit from the results. That is how this demand arising from the needs of some social sectors has become a "resource-basic requirement of a *cross-sectional nature*" (Moral, 2011, p. 159).

2. REGULATIONS VERSUS ARCHITECTURAL BARRIERS

In the past decade or so various regulations instituted requirements for architects, among others, to face and solve these problems that affect wider and wider sectors of our society. In those times references were to *architectural barriers*, a negative term that to a certain extent invoked being "a question of charity, of welfare, of sensitivity, of mere good will" (Pérez, 2011, p. 236). Soon concepts such as accessibility became involved. New terms like handicap and disability arose, while measures to eliminate the barriers that distinguish some individuals from others, the able from the disabled, were adopted; always with the intention of favoring the possibilities of those who did not have full use of all faculties. The legislation of that moment was set within this framework, and its enforceability led to establishing actions; that is, trying to eliminate architectural barriers.

However, this approach is extremely limited, given that it seems to affect a very small part of the population, it does not consider the design of spaces from the beginning, it does not attempt to analyze the causes generating barriers so that they are not created again, and it did not bring about the internalization of the problem by numerous protagonists: the planners. The thing is, if the planners are only involved due to the application of a regulation, the response tends to be reductive, produced by the impulse of an obligation. This means that accessibility is generally seen as a factor outside of the set of decisions making up the project process; such factors are considered in some way unconnected, imposed obligations, to be incorporated in the final stages and usually tackled by looking for special solutions to specific problems, or simply based on technology.

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Projects solved from these approaches satisfy the regulations --they eliminate architectural barriers-- but there is a paradoxical consequence: they are generally discriminatory because they end up constructing a parallel setting for people with disability, the able over here, and those who are not, over there.

3. DIVERSITY AND DESIGN FOR EVERYONE

As we said before, we architects tend to think about prototype individuals when we tackle projects, but we could ask ourselves: what would happen if we considered that those of us who make up our society are much more diverse; that our society also includes children, expectant mothers, the overweight, the ill, and also those affected by a handicap (whether temporary or permanent), and those who have a disability (physical or mental) as well? If we believe that we are a tremendously diverse collective, we should design so that our spaces and cities can be enjoyed by everyone. To understand these requirements, a new sensitivity is also required.

It is surprising how the designer's perception changes if, instead of talking about disabilities, we refer to different degrees of ability; if, instead of thinking about solving some problems in regulations, we internalize accessibility as just another point of the project. And if facilitating access in projects is also considered a factor that improves conditions of use for everyone, even for those without limitations to their abilities.

Accepting diversity, and the fact that there is room in it for the existence of many groups that necessarily require appropriate environments for their full participation as citizens, leads to the approach that it is better to design for any individual, without distinction. This brings up the concept of *Design for Everyone*, whose goal is that environments can be used by all individuals, to the greatest extent possible, and with the characteristic that this idea is included from the very beginning of the design process. This concept, appropriately used, becomes the main tool to achieve *Universal Accessibility*, so that all settings are "understandable, useable, and viable for all individuals in conditions of safety and comfort and in the most autonomous and natural way possible" (Spanish Law 51/2003, p. 7).

Although the goal of *Design for Everyone,* and consequently *Universal Accessibility*, attempts to extend their benefits to all the members of society, obviously there are groups that have greater need of the advantages provided. The most important are those made up of people with permanent disabilities, people with temporary disabilities, or the elderly. But they should also include --in the concept of *others*-- the population formed by children, pregnant women, individuals pushing strollers, those carrying heavy or bulky objects, etc. We should also think about new collectives such as immigrants or tourists, about language barriers, or about the progressive aging of our visitors. Consequently, the benefits from applying these measures are of extraordinary scope.

4. NEW PARADIGMS FOR ARCHITECTURAL DESIGN?

At the present time, diversity having been accepted, design projects have to achieve the desired *Universal Accessibility*; that is, that the benefits of the different services offered can be enjoyed regardless of age, sex, cultural origin, or ability. To carry out this commitment, it is necessary from the beginning to be aware of the requirements involved in the actions and basic activities: Access, Circulate, Communicate, Utilize. Really, these are requirements demanded of any project, except for the fact that, for accessibility, the diversity of the users must be considered. If this issue is kept in mind from the initial stages of the project, if it is implicit in the project approach[1], it will be solved naturally like any other project specification. We can even imagine that the result could turn out enriched.

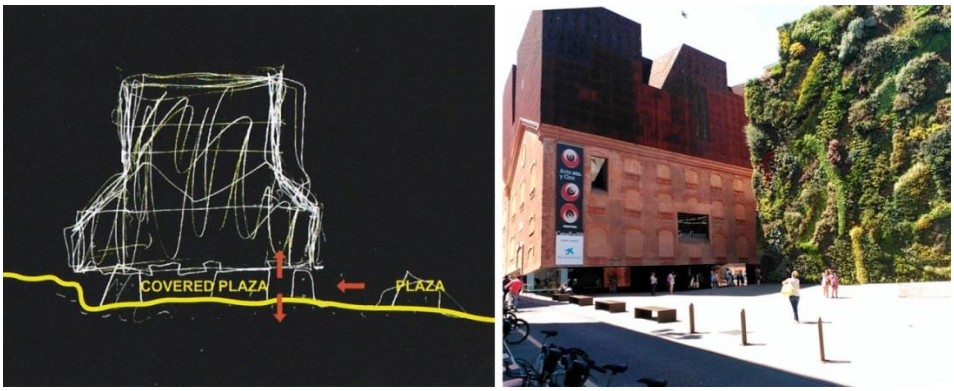

Figure 1. Sketch of the project and view of the CaixaForum.
Source: Drawing: Herzog & De Meuron, El Croquis nº 129-130, p. 339. Photograph: Jové Sandoval, José María.

[1] In the debate on the different concepts that describe the person-environment relationships Iwarson and Staêhl (2003) affirm. "Only if and when human diversity becomes a natural starting point for architectural design and societal planning, the need for special terms will vanish" (p.63).

From this perspective we can analyze, for example, the CaixaForum in Madrid, a project by Herzog & De Meuron. The solution for access to it is a gentle slope that ascends from the *Del Prado* avenue, leading visitors towards the entrance to the museum. Here the hill, inevitable because of the difference in ground height, has been included from the beginning of the design, as well as the idea of converting the plot that previously held a gas station into a public plaza or square covering various parts of the program underneath [Fig. 1]. One of its most characteristic aspects, the buoyancy of the mass of bricks from the ancient thermal center, is established by both its perception from this space and by the structural solution itself. But this spot could have been solved in various ways. Perhaps by a system of stairs and horizontal platforms that would have given greater prominence to the building --by accentuating the difference from the lower level-- and the requirements for accessibility could have been shifted to the lateral street. However, the choice was made to continue the ground like a slight inclined plane that all individuals could traverse. It was after this initial decision that the regulations to adapt the design and fulfill more specific requirements would come.

That said, the concept of accessibility should not be reduced simply to mobility problems, because we would be shrinking the area of our diversity. We should not allow our perception to be reduced to the merely visual, because we would leave many of our senses untouched. Returning to the example of the CaixaForum, it can be pointed out that this building facilitates perception, of course that of visual perception but also many others: walking on and feeling the slope, being enveloped by the shade (and perhaps by its coolness), becoming aware of the weight of the building. There are also olfactory sensations from the smells that can be appreciated, if our sensitivity makes it possible, from the flowers in the plant wall. And, of course, there are sounds from the different areas in the plaza on our way inside.

These *experiences* require the users to put all their sensory abilities into play, which is why they normally go unnoticed. However, there are many people who have these cognitive capacities very developed, for example, those with problems in vision or hearing. Precisely these individuals will be the most sensitive to these values that pervade the architect's work. We can consequently deduce that if we understand our diversity and work with differing abilities --in positive, not with dysfunctions-- we will obtain better results in addition to solving what the regulations require from us.

5. ACCESSIBILITY IN HERITAGE SETTINGS

Dealing with accessibility in heritage settings requires working with the same tools described previously, and with the same attention to the diversity of the people who are going to use them. However, due to the special characteristics of heritage settings[2], there are some specific issues that have to be considered.

In these projects acquiring in-depth knowledge of the heritage element is crucial to proposing the most appropriate solution. It is necessary to know "how it was constructed, what its meaning is, and what its symbolism, its essence, and the feeling that permeates it are" (Juncá, 2011, p. 10). Such knowledge will make it easier to work with judgment, optimizing the element of heritage while solving the needs of accessibility.

It is also very important for the means for resolving these needs be carried out with caution and sensitivity to avoid overlaying materials, diverse building systems, support technologies, or assistive devices that could change the inherent characteristics of the monument. And, always, bearing in mind that the work must be reversible; that is, that the original state can be recovered.

Another key issue is deciding which parts of the heritage element require accessibility, because including the entire extension of the element might be impossible, depending on its characteristics. This matter is important given that the work could represent a disproportionate action --in measures and cost-- or one that undermines the character of the heritage element. Both balance and pragmatism are thus required: "Let us not propose any intervention on our Heritage unless we are sure that this measure is going to be effective in matters of accessibility. Or said in another way, we have to avoid actions that are superfluous and ineffective, and that might additionally alter the Heritage" (Juncá, 2011, p. 11).

One more issue: It is essential to design an accessible route, especially in the area through which it passes, so that it promotes the greatest user knowledge of the heritage element. This condition has to do with what has been expressed before, especially with the overall project approach. We are not talking about only accessibility, but rather about the fact that the route, if it is well planned, will enable understanding of the monument and will transmit its history and its essence; that is, it will make the visitor feel *relation* and *identification* (Ibañez, 2010, p.125). Over the course of the route, there could be proposals for specific places, observation points, alternate pathways, general views, and partial aspects, all of which might offer numerous experiences and

[2] Some might ask themselves: What is the difference between action in the matter of accessibility in heritage settings and in other types of settings? The answer is that the rules and regulations on accessibility are really the same in both cases, except for the various sector provisions that may affect them. Design requirements to solve accessibility for our homes, for our workplaces, and for public buildings and spaces are the same as for heritage settings. The difference lies in how difficult it is to act on cultural heritage due to its specific conditions and its historical value, and because inaccessibility is often its very justification (Garcés, 2010). The design requirements established by accessibility regulations are stable and long-lasting, but they undergo constant review from implementation analysis and from research. That is the way it has been since the time of the first studies on providing the disabled access to public buildings (Parrot, 1980) up to the latest studies on strategies for adapting residential buildings (Fänge and Iwarson 2007).

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perceptive sensations of every type --not just the visual--linked to the special characteristics of the building, ruins, or landscape. In short, it consists of using all the ingredients typical of Architecture correctly.
Lastly, it is a good idea to remember that Cultural Heritage currently plays a decisive role in territorial development thanks to the increase in interest in culture and to the development of tourism, with all the value-added such Heritage entails. Actions to improve accessibility and promote it will boost these ratios. However, they should always be accompanied by criteria for sustainability, among which the fragility of an element in the face of intense use has to be considered as well.

6. LEARNING, PROJECTS FOR THE SAN ANTÓN RUINS

Going deeper into these concepts requires a process of internalization that has to occur during learning. In Architecture schools, these questions are normally treated as collateral issues, perhaps because they have always been considered complementary subjects. However, if they are regarded as authentic design substance, greater commitment from future professionals will probably be attained.
With this in mind, during the 2015-2016 school year the Projects VIII subject --given in the fifth course of the "Architectural Fundamentals Degree" in the School of Architecture at the University of Valladolid (Spain)-- included a project that consisted of work on the ruins of the San Antón monastery. This is a monastery complex from which only the 14th-century church remains. It is located in the open spaces of Castile in a lovely valley with the Garbanzuelo stream flowing through it, alongside the *Camino de Santiago* [Way of St James]. Its link to the Saint James *Camino* was the geostrategic reason behind its location; its precise, carefully chosen placement, protected from the north and fully exposed on its southern exposure, plus the course of the stream and the availability of other fluvial elements such as springs or groundwater, presented many benefits so it could function autonomously. Nowadays its interaction with the landscape and its symbiosis with it are still evident.
Its most characteristic element is the extremely high arcade that rose over the *Camino*. Located between the Church, as a prolongation of it, and the now disappeared hospital, it is known as the *Puerta de San Antón* [Saint Antón's Gate]. Its mysterious, imposing presence has made it a milestone for the pilgrims that have to pass under its arcade on the stretch to Castrojeriz, during their journey to the city of Santiago de Compostela.
The project objectives consisted of recovering the ruins (understood as another element in the landscape) by adding lodging for pilgrims, tasks that would let the students reflect on criteria for working on a Heritage element, its efficient management, and its accessibility. With these premises, the students' work was based on the documentation existing about the monastery complex, the consolidation projects for its ruins, and a trip to the place. This visit permitted the students to delve in depth into the architectural characteristics of the monument, experience its link to the landscape, discover its potential, etc. The next approach to the architectural, topographic, and landscape characteristics was by means of a scale model of the area of activity.

Figure 2. Scale model of a proposal. The *Camino*, the ruins and the project.
Source: Project on the ruins of the San Antón monastery; Left: Torre Macho, Elena; Right: Cuadrado Señorans, Manuel.

CONCLUSIONS

The result of the work was very interesting, presenting widely varied solutions that covered the requirements posed: to construct lodging for the pilgrims following the *Camino* and to attend other visitors attracted by the monument itself [Fig. 2]. Work was based on the premise that the ruins had been consolidated for two decades, so the students only had to work *with* the monument.
To define the character of the project, the students had to consider that the lodging was a special use, only to provide a place to rest and wash up, and a temporary, night-only residence. For other visitors, those who wished to know the monument, a system of reception and information sites about the monastery, along with the possibility of visiting the ruins, were established. Obviously, both aspects were part of the same project and had to be resolved using the same design criteria.

The exercises worked on the presence of the architectural intervention and the dialog with the preexisting pieces, some from their view at a certain distance, in relation to the landscape, and others in the proximity, by means of their materiality, seeking contact and a tactile quality, even acting subtly on the *Camino* itself [Fig. 3]. Improved overall accessibility was posed jointly with the rest of the issues, as a single project. Decisions were made as to the routes of the pilgrims and of visitors, the placement of the lodging pieces and information sites, all in relationship to the ruins or to the surroundings and the predicted movements of the people.

Figure 3. Work on the *Camino* itself.
Source: Project on the ruins of the San Antón monastery; Pérez Fernández, Iago.

The work was hard because of the difference of level between the *Camino* and the interior of the church, as well as the impossibility of knowing the potential of the plot because an archeological excavation would be needed. Many students proposed elevated routes (stilt house-type systems), somewhat distancing themselves from what was happening at ground level; others put themselves at the level of the ground and directly approached the problem of the area, its terrain, and the remains found there. In addition, some students truly worked with the land, searching for its potentialities, sculpting where necessary, constructing where required [Fig. 4].

Figure 4. Stilt house-type proposal. Sculpting the land.
Source: Project on the ruins of the San Antón monastery; Left: Murillo Murillo, Sergio; Right: Pérez Bezos, Silvia.

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The solutions proposed generally sought to produce an *experience* for the visitor. It should be remembered that the monastery ruins lent themselves to this quite well; the project elements made it possible to appreciate the magical atmosphere of that spot and to feel the passing of time, the solidity of its truncated form, and the cold and shadow of its historical walls, among other sensations [Fig. 5]. The placement of the project pieces linked with the most ideal routes (those that provided the best spots for observation), together with the proper choice of materials, attempted to help the visitor discover the best multisensorial perception and the most complete *knowledge* of the place.

Figure 5. The experiences on the route.
Source: Project on the ruins of the San Antón monastery; Left: Piedra Dueñas; Rebeca. Right: Torre Macho, Elena.

To achieve this, the projects used color, texture, material, lighting, shadow, sound, smell, acoustics, temperature, and questions such as form and substance, unique shape, volume, and contrast. All these resources are specific to an architectonic project, but, at the same time, all of them are also factors to be taken into consideration to facilitate physical, sensorial or cognitive accessibility (Ávila, 2015). The importance that the land, its strata, its differences in level, and its discontinuities acquire was also revealed. They all interact with the needs and condition of mobility, not as a problem but as an architectonic value. All of these instruments come from and belong to the world of Architecture, just as usefulness --the "*utilitas"* of the great Vitruvius-- does, which is ultimately the fundamental motive behind this endeavor to achieve universal accessibility.
These are certainly matters of use and perception, and attributes of form and space, in essence material concerning Architecture. However, these tasks have become more and more complex, they cover many more specific details (for example, *orienting oneself* and *tracing* the itineraries, or resolving typography, pictography, and furnishings). Consequently, they should be tackled in a multidisciplinary fashion, in reality, just as any other architectural project of a certain importance.

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