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Measurement and analysis of vibration and shock levels for truck transport in Belgium with respect to packaged beer during transit

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ABSTRACT

Temperature, vibrations and shocks during transport and storage are believed responsible for beer flavour instability. The aim of current study is twofold: (1) to quantify the vibrations and shocks on packaged bottled beer when travelling on the Belgian road network, (2) quantify the impact of the vibrations and shocks in a preliminary experiment.

The spectral density plots illustrate the importance of low-frequency vibrations and the similarities/discrepancies with international standards (ASTM-D4728 and ISO-13355). With increasing stack height, the amplitude of vibrations (5–25 Hz) intensifies in both corrugated boxes and plastic crates. Vibrations > 25 Hz are amplified up to 9 times the original signal depending on the stack height of plastic crates. Corrugated boxes attenuate vibrations > 25 Hz. Corrugated boxes absorb shocks and are preferred over plastic crates with respect to shocks and vibrations. In an exploratory experiment, vibrations and shocks induce the uptake of oxygen and the change of aldehydes (dependency initial oxygen content).

1. Introduction

Postharvest losses of fruit and vegetables, defined as the losses occurring during transport, handling and storage before the food product reaches the consumer, can be as high as 25% of the initial harvested or produced products (Parfitt, Barthel, & Macnaughton, 2010; Van Zeebroeck et al., 2007; Wasala, Dharmasena, Dissanayake, & Thilakarathne, 2015). In the literature, extensive research was done on fruit losses due to vibrations during truck transport (e.g. losses of apples (Van Zeebroeck et al., 2007), pears (Zhou, Su, Yan, & Li, 2007), tangerines (Jarimopas, Singh, & Saengnil, 2005), etc.). Vibrations and shocks, caused by road unevenness and potholes, can directly induce mechanical damage to the products (Lu, Ishikawa, Shiina, & Satake, 2008). In recent studies, researchers also highlighted that a transport load can deteriorate in quality, i.e. changes in the chemical composition of the product, due to vibrations and shocks. An example of the latter phenomenon can be found in the transport of strawberries (Fischer, Craig, & Ashby, 1990; La Scalia et al., 2015). The decline in the sensorial quality of beer during storage was illustrated by several authors (Vanderhaegen, Neven, Verachtert, & Derdelinckx, 2006; Vanderhaegen, Delvaux, Daenen, Verachtert, & Delvaux, 2007). In this paper, the focus is on the identification of transport vibrations and shocks occurring during beer transports, since literature indicated that a decrease in beer quality might also occur during transport (Janssen et al., 2014). However, also more general findings and recommendations regarding packaging materials can be deduced from the findings of this research and extrapolated for food, beverage and electronic products (which is also susceptible to vibration damage). In this regard, under-packaging or the lack of adequate and sufficient packaging to protect a product from damaging, but also over-packaging products should be avoided. Recent estimates indicate that the total cost of over-packaging for all products, in Europe alone, compasses 130 billion per year (Rouillard & Richmond, 2007).

Since beer is increasingly exported, due to market globalization, more often the beverage is subject to longer transportation times and variable storage conditions that lead to an unfavorable decrease in beer flavor (Vanderhaegen et al., 2007). During transport, bottled beer is being exposed to changing temperatures, vibrations and shocks, which may influence the flavor stability. Janssen et al. (2014) signaled that vibrations during transport influence the development of turbidity in beer. However, the exact influence of vibrations and shocks on the beer quality is a research gap that needs to be explored. A first step to perform this research is to identify the (level of) vibrations that occur during beer transports, and this will be the topic of this paper.

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Table 1
Overview transports – vibrations measurements.

Transport (Recording time)	Type Of Transport	Accelerometers	Experimental set-up
* Beer Transport 1 (Rec.time: 9 h 44 min)	Truck transport (trailer with extra trailer with air-ride suspension) [Specifications Appendix A (1)]	Acc 1: on top of a wooden pallet	Plastic crates stacked on top of each other
* Beer Transport 2 (Rec.time: 2 h 28 min)	Truck transport (trailer with air-ride suspension) [Specifications Appendix A (1)]	Acc 2: bottle neck of a bottle in lowest plastic crate/cardboard crate	Plastic crates and cardboard boxes stacked on top of each other
* Beer Transport 3 (Rec.time: 1 h 50 min)	Truck transport (trailer with air-ride suspension) [Specifications Appendix A (1)]	Acc 3: bottle neck of a bottle in highest plastic crate/cardboard crate	Plastic crates and cardboard boxes stacked on top of each other
* Beer Transport 4 (Rec.time: 3 h 26 min)	Truck transport (trailer with leaf spring suspension) [Specifications Appendix A (1)]	[Specifications Appendix A (2)]	Cardboard boxes stacked on top of each other

Consecutively, with improving the quality of beer, the aim is to contribute to a longer shelf life of the beverage as well as an increased customer experience. Similarly to other food products and beverages, it is desirable to extend the shelf life. On the one hand, direct losses due to mechanical damage can be reduced. On the other hand, the quality of the products will directly induce a longer period in which the product can be consumed or, in other words, a longer shelf life of the product.

In literature, vibration levels during truck transport have been studied worldwide: Japan (Lu et al., 2008), Thailand (Jarimopas et al., 2005), Spain (Garcia-Romeu-Martinez, Singh & Cloquell-Ballester, 2008), and multiple other countries (Chonhenchob, Singh, Singh, Stallings, & Grewal, 2012; Rissi, Singh, Burgess, & Singh, 2008; Singh, Singh, & Joneson, 2006; Singh, Jarimopas, & Saengnil, 2006). These publications present a diverse set of parameters that could indicate the origin or the amplifying effects that influence the generated vibrations. Road roughness and speed of driving during transportation are important vibration parameters (Jarimopas et al., 2005; Lu et al., 2008). Jarimopas et al. (2005), for instance, illustrated vibration performance over a diverse set of pavement surfaces. The truck type, payload, and suspension are also relevant parameters. Garcia-Romeu-Martinez et al. (2008) indicated that root mean square (RMS) and peak vibration can be reduced by 50% by using a truck with an air-ride suspension over a leaf-spring suspension. Other relevant parameters that influence vibration levels are platform location (Zhou et al., 2007), vibration direction (Singh, Antle, & Burgess, 1992) and tires (Jones, Holt, & Schoorl, 1991).

The aim of the current work was to identify the level of vibrations and shocks bottled beer is subjected to when transporting by truck, and using different packaging modalities, and, additionally, to assess the impact of vibrations and shocks on the beer flavor quality (case-study). There are three transport modes that are regularly used to transport beer: trucks, trains, and ships. The scope of this paper was limited to vibration analysis of truck transport (leaf spring and air-ride suspension) in Belgium. Research on truck vibrations is extensive and has expanded considerably in last years. However, the relation between vibrations and shocks during transport with product packaging is often missing or underdeveloped in literature (Eissa, Gamaa, Gomaa, & Azam, 2012). This emphasizes the unique contribution of this paper. The current research was also limited to bottled beer stacked on top of each other in cardboard boxes and plastic crates, the two most commonly used packaging modalities for beer. Plastic crates are frequently used for domestic transportation, due to the recycling logistics of the crates, while cardboard boxes are especially used for transports to foreign countries. Furthermore, the transmissibility of the pallet vibrations to the highest stacked crates is identified and, therefore, the insights of the interaction between vibrations and bottled beer could be extended to other geographical regions by changing the (input) vibration spectra or the amplitude of the vibrations. Bottled beverages that suffer quality deterioration (for instance wine (Chung, Son, Park, Kim, & Lim, 2008)), or other food products (for instance strawberries (Fischer et al., 1990)) could use these findings to further develop their research study.

2. Materials and methods

2.1. Experimental design

For the purpose of this research, vibration measurements were performed on four (beer) transports, three transports with an air-ride suspension truck and one truck transport with a leaf spring suspension. All truck transports were executed over the Belgian road infrastructure. The road typology in Belgium can be categorized as national highways, highways and local or rural roads. Highways are major roads that connect districts and large cities and make able to transport freight over medium and long distances. In current study, the Belgian national highways that were studied are predominantly paved with asphalt. The highways are paved both by asphalt and by concrete, while rural roads are predominantly paved by asphalt but exceptionally by cobblestones. Since attention was given on the validity and significance, the presented results are findings from traveling by truck over all different roads and measured on four different transports.

Table 1 presents an overview of the transports that were attended by the author of this study. The number of transports made able to benchmark and validate the results. As an experimental set-up, plastic crates, as well as cardboard boxes, were stacked on top of each other (5–7 boxes/crates on top of each other). Three accelerometers were used: one accelerometer was mounted on the floor of the container (on top of the wooden pallet), and two accelerometers on the bottleneck of two beer bottles (Fig. 1a) that were located in the stacked crates or boxes (Fig. 1b and c). In order to not influence the interaction between the bottle and the packaging, the accelerometers were mounted on the beer bottleneck. Since food products are transported on wooden pallets, vibrations were measured on the pallet itself and not on the container floor. The aim was to discover the transmissibility of the pallet vibrations to the vibrations beer bottles are exposed to in their beer packaging. During all transports, a camera (GoPro Hero 4) was mounted on the seat of the truck driver to visually capture the road characteristics and the driving speed. Vibrations measurements were performed during transports with full, empty and varying cargo load.

In order to quantify the vibration response during beer transports, vibration measurements were performed with the following experimental set-up. A laptop was connected to a data acquisition board (National Instruments USB-6361), which was connected to different accelerometers. The accelerometers (Sparkfun ADXL 337), mounted on the pallet and on the beer bottlenecks, measured acceleration in three directions. Most research articles on vibrations during transport analyze vibrations up to 100 Hz (Berardinelli, Donati, Giunchi, Guarnieri, & Ragni, 2003; Jarimopas et al., 2005), in this study the Nyquist-frequency was fixed sufficiently higher to also evaluate the influence of high-frequency vibrations. The accelerometers, which have a bandwidth of 1600 Hz (X- and Y-axis/noise density: 175 μg/√Hz rms) and 550 Hz (Z-axis/noise density: 300 μg/√Hz rms), had a sample rate of 1e5 samples per second. The total set-up was powered by an external battery and transformed to the necessary voltage using a transformer (Voltcraft SWD-300/12).