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Impact of water rinsing and perforation-mediated MAP on the quality and off-odour development for rucola

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ABSTRACT

Rucola is an important leafy green salad normally sold in plastic trays wrapped with macro-perforated polypropylene film without modified atmosphere. The objectives of this study were to optimize the packaging system and to investigate the effects of water rinsing prior to packaging of rucola on changes in quality and accumulation of volatile organic compounds (VOCs). Washed and unwashed rucola were packed using different packaging systems: without perforations (MAP-0); optimized 2 micro-perforations of 0.5 mm diameter (MAP-2); and 21 macro-perforations with 5 mm diameter (Control). Gas composition in control packages stayed close to air, while MAP-0 led to anoxia, and for MAP-2 equilibrium modified atmosphere was achieved by day 2 of storage within the range of 2–3% O_2 and 10–12% CO_2. Browning of cut edges, water loss, and loss of turgor pressure was most severe for samples in the control packages. Degradation of rucola quality attributes was delayed under MAP-2. A total of 33 VOCs were tentatively identified via GC–MS, consisting of 18 primary (detected on fresh samples prior to storage) and 15 secondary (detected on samples during storage) VOCs. Accumulation of secondary VOCs and development of strong off-odour was higher for washed samples in comparison to unwashed samples. MAP-0 led to development fermentative off-odour by day 3 of storage. Perceived development off-odour based on sensory evaluation was observed to be consistent with the accumulation of ethyl esters, benzaldehyde and benzeneacetaldehyde volatiles. This highlights the critical need for integrated packaging and cold chain design for individual fresh produce.

1. Introduction

Eruca Vesicaria ssp. *sativa* (P. Mill.) Thellung, commonly known as "Ackerrauke" in Germany, "rucola" in Italy, or "arugula" or "garden rocket/rocket salad" in the United States, belongs to the *Brassicaceae* family (Jirovetz, Smith, & Buchbauer, 2002). Rucola is an edible low calories green leafy vegetable (herb) that has become increasingly popular within the last two decade. It is eaten raw as fresh salad, or as a steamed vegetable, and in sauces (Cavaiuolo and Ferrante, 2014). Major challenges affecting the postharvest quality and shelf life of fresh rucola during storage are: the continued physiological processes as a result of respiration, the development of strong off-odours, tissue flaccidity and sensitivity of cut edges to browning, mechanical damage, and microbial decay associated with liberated nutrients from injured tissues (Cantwell, Rovelo, Nie, & Rubatzky, 1998; Nielsen, Bergström, & Borch, 2008). This results in a shorter shelf life due to leaf yellowing, which is accompanied by other degradation processes. The shelf life of fresh rucola leaves stored at 0, 5 and 15 °C were studied by Amodio, Derossi, Mastrandrea, and Colelli (2015), which described the kinetics of the most important quality attributes of rucola by used Weibullian model. The shelf life significantly changed, depending on storage temperature and thermal quality attributes. When the samples were stored at 5 °C, the appearance limited the shelf life up to 5.8 days.

Rucola is normally sold in plastic trays wrapped with macro-perforated polypropylene film in most of the German supermarkets. Such packaging system prevents wilting and eases of the handling and marketing of the product. However, the macro-perforated packaging system leads to very high gas permeability (Hussein, Caleb, & Opara, 2015; Hussein, Caleb, Jacobs, Manley, & Opara, 2015); therefore, it does not allow to atmosphere modification inside the package resulting in loss of freshness and green chlorophyll pigments. Hence, the major drawbacks associated with packaging leafy green vegetables under modified atmosphere packaging (MAP) systems are; that under sub-optimal MA conditions anaerobic metabolism can be induced and inappropriate packaging allows for accumulation of volatile

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organic compounds (VOCs) in the package headspace, which can significantly influence the secondary volatiles generated (Nielsen et al., 2008; Caleb, Mahajan, Al-Said, & Opara, 2013; Caleb, Opara et al., 2013; Tudela et al., 2013). Furthermore, fresh rucola has a characteristic pungent, sharp, and peppery flavour attribute, which has been attributed to the breakdown of glucosinolates into simple molecules such as isothiocyanates (Jirovetz et al., 2002; Miyazawa, Maehara, & Kurose, 2002; Bennett, Rosa, Mellon, & Kroon, 2006). Several studies have shown that the characteristic flavour attributes related to VOCs for packaged fresh or fresh-cut produce changes significantly during storage. This results in either loss of freshness odour and/or the accumulation of off-odour VOCs towards the end of storage (Edelenbos, Seefeldt, & Løkke, 2015; Caleb, Ilte, Fröhling, Geyer, & Mahajan, 2016). The development undesirable odours inside packaged rucola during storage are a problem that has been consistently identified by the food processing industry. Therefore, there is still a need to optimize the packaging system for fresh rucola along the cold chain and retail display.

Modified atmosphere packaging (MAP) combined with cold storage is widely used to maintain quality attributes and extend the shelf life of leafy green vegetables, based on the modification in gas composition inside the package. This helps to slow down produce physiological as well as metabolic processes, thereby, preserving the freshness and marketability (Mahajan, Caleb, Singh, Watkins, & Geyer, 2014; Borchert et al., 2014). It is well established that the gas composition inside MAP filled with fresh produce becomes modified due to the gas permeability properties of the packaging material, the respiration rate of the produce, the weight of the produce, and the free volume of the package (Mahajan, Oliveira, Montanez, & Frias, 2007; Hussein et al., 2015; Hussein, Caleb et al., 2015; Belay, Caleb, & Opara, 2016). Fill weight and package size are often pre-determined factors and therefore, the only controllable variable is the gas permeability of the lidding film which can be optimised with suitable micro-perforations in order to achieve equilibrium modified atmosphere.

The use of various antimicrobial rinsing/dipping solutions have been extensively reported in literature for leaf green vegetables (Martínez-Sánchez, Allende, Bennett, Ferreres, & Gil, 2006; Tudela et al., 2013), their industrial application are limited due to existing food regulations and public health implications. For rucola distribution there remains a critical lack of an optimum integrated postharvest treatment step and package design system, which is applicable across the cold chain. This further compounds the identified challenges. Thus, the objectives of this work were to optimise the packaging system for fresh rucola, evaluate its performance under two different time-temperature profiles normally observed in rucola supply chain in Germany, and investigate the impact water rinsing and packaging systems on the development of off-odour and quality of rucola.

2. Materials and methods

2.1. Plant material and processing

Rucola (*Eruca Vesicaria*) was grown and harvested by a commercial grower (Gemüsering, Stuttgart, Germany). After harvest leaves were vacuum-cooled and shortly stored at 4 °C and ≥95% relative humidity until packaging. Leaves were thereafter divided into two groups for unwashed and washed treatment prior to packaging. Washed rucola was dipped in water for 30 s and centrifuged to remove excess water.

2.2. Packaging and storage

Rucola leaves were weighed (125 g) into polyethylene terephthalate trays (185 × 145 × 70 mm), which were then covered with oriented polypropylene film. Each tray was flow wrapped in polypropylene film (30 μm thickness). Three different packaging treatments with different perforation levels were used (Table 1). The size and number of micro-perforations required for optimum modified atmosphere (MAP-2) were calculated using mathematical modelling approach based on respiration rate of fresh rucola (Mahajan et al., 2007). Respiration rate of fresh rucola was quantified before the packaging operation. All the packaging and perforation operation was performed on the commercial packaging line (Gemüsering, Stuttgart, Germany).

The packaged rucola were transported overnight in a commercial cooling truck maintained at 10 °C to the Department of Horticultural Engineering, Leibniz Institute for Agricultural Engineering and Bioeconomy and immediately stored at 4 °C, 80% RH in a walk-in cooling room. The packages were divided into two cold chain-regime groups: each group was stored at two different temperature profiles (Table 1), in order to mimic the supply chain and retail/consumer temperature abuse practices of packaged rucola. Overall, there were 12 treatments consisting of 2 types of rucola (washed and unwashed), 3 types of packaging systems and 2 types of cold-chain management systems. Three replicate packages from each treatment were sampled for quality analysis at 3 different stages (beginning of storage, transition from low to high temperature, and at the end of storage period). In total, 108 packages were used in this experiment.

2.3. Package performance evaluation

Headspace gas composition (O_2 and CO_2) of rucola packages was measured at regular intervals using gas analyzer (PBI Dansensor, Ringsted, Denmark). After gas measurement, the mass of each package was recorded. The mass loss was calculated as the total loss of mass in percentage of the initial mass weight of the package (Rux et al., 2015). Respiration rate of rucola (125 g) was determined on each sampling day at 4 °C and 20 °C using in-house

Table 1
Experimental plan for packaging and storage of rucola.

Factors	Variables
Rucola treatments:	a) Washed leaves b) Unwashed leaves
Packaging treatments:	a) MAP-0: No perforations b) MAP-2: 2 micro-perforations of 0.5 mm diameter (optimized based on rucola physiological data) c) Control: 21 macro-perforations of 5 mm diameter
Storage treatments:	a) Short-term cold chain, 2 days at 4 °C, 80% RH + 4 days at 20 °C b) Long-term cold chain, 4 days at 4 °C, 80% RH + 3 days at 20 °C