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Effects of ethylene and 1-MCP on ripening and senescence of European seedless cucumbers

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Abstract

The effects of exogenous and endogenous ethylene combined with or without the ethylene action inhibitor, 1-methylcyclopropene (1-MCP), on the shelf-life of European seedless cucumbers (*Cucumis sativus* L.) were studied. Exogenous ethylene (3–5 $\mu l\,l^{-1}$) accelerated the breakdown of chlorophyll but the degradation pathway was not altered by ethylene treatment. Chlorophyll catabolism in cucumbers seems to follow the same pathway as in parsley with replacement of Mg^{2+} as the first step with a minor role for chlorophyllide, followed by oxidative ring cleavage of the pheophytin *a* formed. Degreening was accompanied by an increasing amount of citric acid in the endocarp with a concomitant fall of malic acid but with the onset delayed until 50% of the chlorophyll had disappeared. Fresh cucumbers, fumigated with 1-MCP before continuous exposure to ethylene, did not deviate from those untreated, with inhibited chlorophyll degradation for 14 days in one experiment, but for only 9 days in another experiment, after which 1-MCP + ethylene resulted in a patchy degreening of the peel. However, in pre-stored fruit either continuously exposed to propylene or air, fumigation with 1-MCP prior to exposure did not prevent degreening indicating that breakdown of chlorophyll in aged fruit may be triggered and regulated by developmental factors and not by the low level of endogenous ethylene produced. It is therefore concluded that cucumbers probably show little benefit from fumigation with 1-MCP unless exogenous ethylene is present. Although the cucumbers were harvested before one quarter of the final weight was reached, they were able to develop the same ripening characteristics, i.e. yellowing, accumulation of citrate and tissue softening as if left on the plant until growth has ceased. These results suggest that cucumber ripening and senescence are overlapping processes and internal factors activating senescence-associated genes probably determine the keeping quality of cucumbers.

Keywords: Cucumbers; Chlorophyll; Organic acids; 1-MCP; Ethylene; Ripening; Senescence

1. Introduction

Glasshouse grown European seedless cucumbers (*Cucumis sativus* L.) are rapid developing fruit harvested before growth has ceased and consumed unripe when commercially mature. Size, shape and a dark green colour of the peel indicating freshness are the only maturity indices demanded by the market.

Shelf-life, expressed as the number of days from harvest to incipient yellowing due to chlorophyll (Chl) breakdown, is reported to vary considerably between

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fruit with the same colour at harvest and stored under equal conditions (Schouten et al., 2002). Fruit growth follows a single sigmoid pattern but the time lag after anthesis can vary considerably before harvest size is achieved 9–24 days after anthesis (Marcelis, 1992), probably due to variation in fruit load on the plant and daily solar radiation. Shelf-life was reported to be positively correlated with fruit colour at harvest and negatively correlated with number of days needed to obtain harvest size (Lin and Ehret, 1991). If a constant rate of Chl loss is assumed, fruit with an initial high level should consequently have a longer shelf-life.

Citric and malic acid are the predominant organic acids with malic acid as the major acid in fruit of commercial size (McFeeters et al., 1982). Saltveit and McFeeters (1980) reported a decreasing pH from 5.2 to 3.3 in the endocarp tissue due to accumulation of citric acid. As the declining pH was concomitant with loss of Chl, they assumed it was a ripening-related process. Although decreasing acidity is a common feature of fruit ripening, fruit of several botanical varieties of *Cucumus melo* are more sour than sweet when ripe (Mallick and Masui, 1986).

Cucumber ripening also involves tissue-softening starting in the endocarp similar to watermelon (Karakurt and Huber, 2002). The decreasing endocarp pH was matched by an enhanced polygalacturonase activity (Saltveit and McFeeters, 1980) but tissue softening during marketing seems not to be a serious problem compared with yellowing.

Cucumbers are classified as non-climacteric by Biale and Young (1981). Among other cucurbits, watermelons are also regarded as non-climacteric (Elkashif et al., 1989) but possess a fruit ripening behaviour (Seymour and McGlasson, 1993). A low ($<0.1\ \mu l\ kg^{-1}\ h^{-1}$) system I ethylene production is present in unstressed cucumbers (Mathooko et al., 1995) but low temperature stress, wounding and pathogen infection (Abeles et al., 1992) increase the ethylene production due to an enhanced activity of ACC synthase.

It is well known that exposure to ethylene accelerates senescence of vegetables with yellowing, tissue softening and microbial growth as well as certain ripening-related events in many non-climacteric fruit (Vendrell et al., 2001). Since these activities also take place during normal ripening in the absence of exogenous ethylene, it cannot be excluded that the low ethylene production may have a role in the ripening process of some but not all non-climacteric fruit (Goldschmidt, 1997).

Glasshouse cucumbers attached to the plant turn yellow when growth terminates, but when harvested green, yellowing is normally delayed for several days. Cucumbers are, however, very sensitive to low amounts ($0.1–1\ \mu l\ l^{-1}$) of exogenous ethylene (Apeland, 1961) with an enhanced yellowing of the peel and tissue decay.

Whether Chl breakdown in the peel, increased citric acid content and tissue softening of cucumbers harvested unripe are part of a delayed senescence syndrome or a fruit ripening process is still an open question.

The advent of volatile ethylene antagonists such as 1-methylcyclopropene (1-MCP) recently reviewed by Blankenship and Dole (2003) has provided a tool for investigations of the role of ethylene in ripening and senescence-related processes in non-climacteric fruit. 1-MCP was reported to delay Chl degradation in oranges (*Citrus sinensis*) (Mullins et al., 2000), and prevent broccoli yellowing (Fan and Mattheis, 2000). The use of 1-MCP as a tool to secure postharvest colour retention of glasshouse cucumbers therefore ought to be tested.

The aim of the present study was to evaluate the effects of endogenous and exogenous ethylene on ripening and senescence related processes in glasshouse cucumbers by means of 1-MCP. Breakdown of Chl, changes in the amounts of organic acids, rate of respiration and endogenous ethylene production during storage in darkness at 20 °C were investigated. Besides ethylene, treatment with propylene, an active ethylene analogue, was included to quantify low amounts of endogenous ethylene produced.

2. Materials and methods

2.1. Fruit

In the first experiment, fresh parthenocarpic glasshouse cucumbers (*Cucumis sativus* L. cv. Sabrina NS) grown in The Netherlands were purchased from a wholesaler. In the other experiments cucumbers cv. Armada RZ were obtained from a local commercial grower on the day of harvest. All cucumbers were