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Improving Quality and Extending Shelf Life of Intact and Minimally Fresh Processed Kohlrabi

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ABSTRACT

In recent years the increased demand of kohlrabi from European Nordic countries has induced an expansion of their cultivated area in Spain. Commonly, at the retail sale level kohlrabi stems are mainly commercialized in ambient air under non-refrigerated conditions. For that reason, weight loss, development of diseases, and an increase in toughening are the most important causes of kohlrabi deterioration. The storage life of kohlrabi stems stored with leaves is only 2 weeks at 0ºC and 95% relative humidity (RH). Nevertheless, when the stems are stored without leaves the storage life could be prolonged up to 2 months at 0ºC and 95% RH. On the other hand, the minimal fresh processing of kohlrabi stems to produce ready-to-eat slices, dices and sticks increases the deterioration rate. The use of controlled and modified atmospheres (CA and MA) benefits the overall quality and shelf life of whole intact and minimally fresh processed or fresh-cut kohlrabi, mainly by reducing water loss, the respiration rate and the ethylene production, retarding microbial growth and decay, and inhibiting some disorders like enzymatic browning. According to our studies the range of 2 to 5 kPa O_2 combined with 5 to 20 kPa CO_2 at 0 to 5ºC and 95% RH are the most appropriate conditions for lowering the metabolic activity and microbial growth. This review describes the effect of low O_2 combined with different CO_2 levels on the respiration rate, ethylene production, sugars and organic acids content, microbial growth, physiological disorders and shelf life of intact and minimally fresh processed kohlrabi.

Keywords: *Brassica oleracea*, chemical parameters, controlled and modified atmosphere quality attributes, ethylene production, fresh-cut, microbial growth, respiration rate

CONTENTS

INTRODUCTION

Kohlrabi (*Brassica oleracea* L. *gongylodes* group) is a member of the *Brassicaceae* (mustard) family. Kohlrabi is grown for its slightly flattened, round swollen stem at the base of the plant. The leaves extend directly from the swollen stem. It is a low biennial plant native to northern Europe but it grows better under cool and humid climates. However, an increase in demand from Germany, Austria, Switzerland, and other northern EU countries has allowed an expansion of the cultivated area in the Spanish Mediterranean zone. In Spain, the harvest season for kohlrabi extends from November to March. It requires 50 to 65 days from seed to harvest with a production of 35 to 45 t ha^{-1} (Maroto 1995; Namesny 1996). Depending on the cultivar, kohlrabi stems may be white, purple, or green but with a flesh always white. Stems should be harvested when they reach 8 cm in diameter. Stems harvested with a smaller diameter are fresher and tenderer and they do not require peeling.

The most important problems on kohlrabi deterioration during chilling storage are weight loss, development of diseases, and increased toughening (Namesny 1996). The storage life of kohlrabi depends on whether stems are stored with or without leaves. When they are stored without leaves they can be stored for 3 months at 0ºC with 98-100% RH to prevent shrivelling and toughening. However, when stems are kept with their leaves the storage life is reduced to about 2 weeks at 0ºC (Hardenburg *et al*. 2004). The ideal storage condition should be at or near 0ºC to prevent the development of diseases, mainly bacterial soft (*Erwinia caratovora*

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and *Pseudomonas* pp.) and black rot (*Xanthomonas* spp.) (Hardenburg *et al*. 2004). Cantwell (2002) reported that there is no benefit of controlled atmosphere (CA) on the fresh quality of whole kohlrabi. However, Saray (1994) showed that stems with leaves can be maintained in low O_2 at -1 to 1ºC for 2 weeks decreasing the respiration rate and microbial growth. Nowadays, for the retail sale period, kohlrabi stems are mainly sold in air ambient under non-refrigerated conditions. Respiration data of fresh vegetables are showed in **Table 1**.

An alternative market to intact vegetables in foodservice and retail sale markets are the minimally fresh processsed or fresh-cut products. The minimally processed business has grown exponentially in Europe and the USA. Consumer preferences are increasingly towards ready-to-eat or ready-to-use fruit and vegetables. Injury stresses due to operations such as peeling, cutting, shredding or slicing greatly increase tissue respiration, leading to biochemical deterioration like enzymatic browning, texture breakdown, off-flavour and risk of microbial development. In particular, the respiratory activity and ethylene production are, commonly increased, especially during the first hours after they have been cut, peeled or shredded, and depending on the grade and severity of the processing. For all those reasons the cut product has a shorter shelf life than the whole original (Watada *et al*. 1996; Artés *et al*. 2007). In general, the shelf life of an intact product compared to fresh-cut vegetables is two or three times longer due to the damage caused by cutting, which accelerates metabolism and senescence (Huxsoll and Bolin 1989; Varoquaux and Wiley 1994; Ahvenainen 1996; Artés *et al*. 2007). To extend the shelf life and to keep a good overall quality during storage, handling, distribution and retail sale of minimally processed vegetables it is recommended to combine the use of modified atmosphere packaging (MAP) technique with 1 to 8 kPa O_2 plus 10 to 20 kPa CO_2 at 0º to 5ºC (Huxsoll and Bolin 1989; Varoquaux and Wiley 1994; Ahvenainen 1996; Gorny 1997; Artés *et al*. 2006). As for intact vegetables, MA benefits minimally processed products decreasing their metabolic activity, microbial growth and some physiological disorders such as enzymatic browning (Varoquaux and Wiley 1994; Watada *et al*. 1996; Gorny 1997; Artés *et al*. 2006). In **Table 2**, recommendations of gas atmospheres and storage temperatures are provided for some fresh-cut fruits and vegetables. Studies on postharvest behaviour of intact and minimally processed kohlrabi are scarcely reported. Hardenburg *et al*. (2004) reported that peeled and sliced kohlrabi could have potential as a new fresh-cut product and they do not produce strong off-odours under low O_2 levels.

This review reports recent results about the effect of low O_2 combined with different CO_2 levels on the respiretion rate, ethylene production, sugars and organic acids content and microbial growth of intact stems as well as of minimally processed kohlrabi. In addition, the main changes in quality attributes during transport, distribution and retail sale periods of kohlrabi are reported.

Table 1 Classification of fresh vegetables according to their respiration rate at 5ºC.

Relative respiration rate (mL CO_2 kg^{-1} h^{-1})	**Commodities**
Very low (less than 5)	Dried vegetables
Low (5 to 10)	Garlic, onion, potato (mature), sweet potato, **kohlrabi**, fennel
Moderate (10 to 20)	Cabbage, carrot, lettuce, pepper, tomato, potato (immature)
High (20 to 40)	Cauliflower, lima bean
Very high (40 to 60)	Artichoke, snap bean, green onion, brussel sprout
Extremely high (above than 60)	Asparagus, broccoli, mushroom, pea, spinach, sweet corn

Adapted from the International Fresh-cut Produce Association.

Table 2 A summary of CA and MA requirements and recommendations for some intact and fresh-cut fruits and vegetables.

Products	**Optimal storage temperature (ºC)**	**Atmosphere O_2**	**Atmosphere CO_2**	**Shelf-life (weeks)**
Celery	4	5	15	5
Celery sticks	4	6	7	3
Fennel	0-5	2 - 5	5 - 15	4
Fennel slices	0 - 5	2 - 5	15 - 20	2
Kohlrabi (leaves)	0 - 5	3 - 5	10 - 15	2- 4
Kohlrabi (without leaves)	0 - 5	3 - 5	10 - 15	4 - 8
Kohlrabi slices	0 - 5	5	15	1 - 2
Lettuce	0 - 2	2 - 5	0	2 - 3
Lettuce (shredded)	0 - 5	1 - 3	5 - 6	1 - 2
Galia and Cantaloupe melon	3 - 7	3 -5	10 -15	2
Amarillo melon (trapezoid)	0 - 5	4	15	2
Pomegranate	2 - 7	3 - 5	5 -10	6 -12
Pomegranate arils	2 - 5	1 - 3	5 - 10	1 - 2
Tomato (green/breaker)	8 - 12	3 - 5	1 - 3	2 – 4
Tomato (pink/red)	8 - 12	3 - 5	1 - 5	1 – 3
Tomato slices	1 - 5	2	20	1 - 2

Adapted from Artés *et al*. 2006.

QUALITY CHANGES OF KOHLRABI DURING COLD STORAGE

Respiration rates

Kohlrabi has a low respiration rate when it is stored under cold temperatures. Escalona *et al*. (2003, 2007a) reported respiration rates of stems with leaves of 16 to 20 mg CO_2 kg^{-1} h^{-1} in air at 0ºC and 95% RH during the first three days of storage. These rates progressively declined to 5 to 10 mg CO_2 kg^{-1} h^{-1} after 14 days at 0ºC. Meanwhile, kohlrabi stored in air at 5ºC had 7 to 9 mg CO_2 kg^{-1} h^{-1} reaching higher respiration rate of 17 mg CO_2 kg^{-1} h^{-1} after 27 days (Escalona *et al*. 2006). Hardenburg *et al*. (2004) have reported a respiration rate of 10 and 31 mg CO_2 kg^{-1} h^{-1} at 0º and 10ºC, respectively. Others authors have considered kohlrabi stems as vegetables with a low respiration rate (9.7 to 19.3 mg CO_2 kg^{-1} h^{-1}) in air at 5ºC (Kader and Salveit 2003).

Respiration rates of kohlrabi stems in CA were lower than those in air. Under CA of 5 kPa O_2 + 5 kPa CO_2, the

Table 3 Respiration rate (mg CO_2 / kg h) of intact stems and slices of kohrabi 'Kompliment F1' cv. in different atmospheres for 27 and 14 days at 5°C respectively. Means (n = 5) ± SE.

Days at 5ºC	**Controlled atmosphere (kPa O_2 / kPa CO_2)**					
	21 / 0		**5 / 5**		**5 / 15**	
	Stems	**Slices**	**Stems**	**Slices**	**Stems**	**Slices**
2	8.4 ± 0.8	9.6 ± 0.8	3.4 ± 0.1	3.5 ± 0.1	5.2 ± 0.9	6.7 ± 0.9
4	9.6 ± 0.9	10.9 ± 0.9	3.0 ± 0.9	3.4 ± 0.9	4.6 ± 1.2	7.6 ± 1.2
8	9.6 ± 0.9	8.7 ± 0.9	3.8 ± 0.9	4.0 ± 0.9	5.8 ± 0.5	4.5 ± 1.2
10	6.5 ± 0.4	5.8 ± 0.4	2.0 ± 0.3	1.7 ± 0.3	4.5 ± 0.3	5.5 ± 0.3
14	9.0 ± 0.8	7.4 ± 0.8	4.1 ± 0.5	1.7 ± 0.5	4.4 ± 1.0	5.0 ± 1.0
21	10.6 ± 0.9	nd	1.8 ± 0.2	nd	2.2 ± 0.5	nd
28	17.0 ± 0.9	nd	4.4 ± 1.0	nd	5.5 ± 0.5	nd

respiratory activity ranged from 2 to 4 mg CO_2 kg^{-1} h^{-1} (**Table 3**). In contrast, under CA of 5 kPa O_2 + 15 kPa CO_2 the respiration rates were slightly higher reaching 4 to 6 mg CO_2 kg^{-1} h^{-1} (Escalona *et al*. 2006). Generally the effect of lowering the respiratory activity can be related to low O_2 level. Kader (1986) reported that by using 1 to 5 kPa O_2 aerobic respiration is reduced avoiding anoxia of vegetable tissue.

Minimally fresh processed kohlrabi

When intact kohlrabi stems are minimally fresh processed the metabolic activity increase reducing the quality and storage life. The wound stress caused by cutting induces many physical and physiological responses such as an increase in respiration and ethylene production as well as in enzymatic activity. For that reason, the tissue response usually increases when the level of the injury is increased (Cantwell and Suslow 2002; Artés *et al*. 2007). As a result, higher CO_2 production in dices of 1 cm^3 compared to intact stems was obtained by the severity of cutting (Escalona *et al*. 2003). Meanwhile in air at 5ºC, slices of 0.8 cm thickness showed a respiration rate close to that of the intact stems (**Table 3**). This result would indicate that by slicing the kohlrabi flesh was less damaged (Escalona *et al*. 2006). In CA of 5 kPa O_2 + 5 kPa CO_2 at 5ºC, kohlrabi slices had a very low respiration (2 to 6 mg CO_2 kg^{-1} h^{-1}) increasing slightly when the CO_2 level was increased to 15 kPa (Escalona *et al*. 2006). Therefore, the low respiration rate of stems and slices under CA compared to air could be related to low O_2 level of 5 kPa.

Ethylene production

In agreement with Kader (2002) kohlrabi should be considered as a vegetable with a very low C_2H_4 production. Escalona *et al*. (2003, 2007a) reported ethylene production lower than 0.05 µL kg^{-1} h^{-1} for kohlrabi stems at a temperature range from 0 to 10ºC. Earlier, Hardenburg *et al.* (2004) found very low ethylene production, less than 0.1 µL kg^{-1} h^{-1}, even when stems were stored at 20ºC. These authors also reported the sensitivity of intact kohlrabi to low external ethylene exposure, but data was not mentioned. According to other study, kohlrabi stems showed sensibility to ethylene levels below 0.05 µL L^{-1}. Also a high C_2H_4 production of stems due to the abscission of stalks and decayed growth as senescence deterioration was observed after 21 days at 5ºC in air (Escalona *et al*. 2006).

Minimally fresh processed kohlrabi

After cutting such as sticks (1 x 1 cm) an increased C_2H_4 production (0.13 µL C_2H_4 kg^{-1} h^{-1}) compared to intact stems at 5ºC was detected. However, the ethylene production progressively declined throughout cold storage to 0.01 µL C_2H_4 kg^{-1} h^{-1} (Escalona *et al*. 2007c). A similar pattern was found in kohlrabi slices, although in this case, ethylene production after cutting was 0.07 µL C_2H_4 kg^{-1} h^{-1} decreasing to 0.01 µL kg^{-1} h^{-1} at the end of the storage at 5ºC (Escalona *et al*. 2006). Previous studies reported low C_2H_4 production (less than 0.05 µL kg^{-1} h^{-1}) of kohlrabi dices at 0°C (Escalona *et al*. 2003).

Modified atmosphere packaging

The quality retention of intact and fresh cut products can be maximized when proper temperature management is used combined with optimum MAP. The benefits of the use of MAP are well known, but its effect depends on species and cultivar (Watada *et al*. 1996; Artés *et al*. 2006). Escalona *et al*. (2007a) researched the advantages of MAP in kohlrabi stems. They reported that a proper equilibrium atmosphere to maintain the fresh sensorial quality of kohlrabi is generated by a balance between respiration rate and weight of product and gas permeabilities and the area of the polymeric film. Oriented polypropylene of 20 or 40 µm provided gas composition of 5 kPa O_2 + 10.5 kPa CO_2 recommended for kohlrabi at 0ºC (**Fig. 1**). The ethylene concentration reached within those bags after cold storage and retail sale period was lower than 0.2 mL L^{-1}.

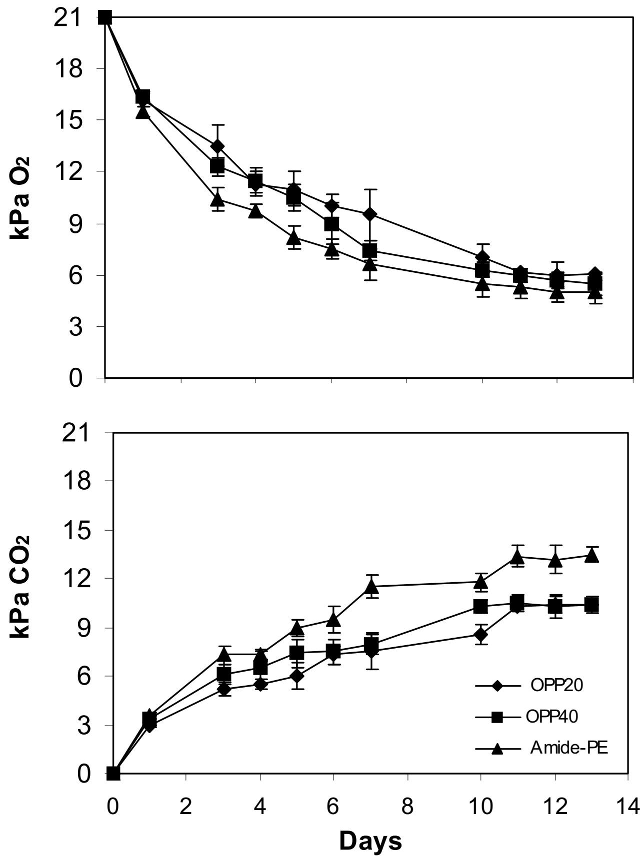

Fig. 1 Gas composition changes (O_2 and CO_2) in kohlrabi stems 'Kompliment F1' cv. under MAP up to 14 days at 0ºC. Means (n = 5) ± SE.

Minimally fresh processed kohlrabi

An optimal O_2 and CO_2 mixture can be obtained by using OPP films of 20 to 35 µm for keeping a good appearance and freshness. A steady atmosphere of 6 to 13 kPa O_2 + 8 to 14 kPa CO_2 was obtained in kohlrabi dices packed in OPP (35 µm) at 0ºC. However, kohlrabi sticks (1 x 1 cm) packed in OPP (20 µm) bags reached 9.5 to 10 kPa O_2 and 7 to 7.5 kPa CO_2 kPa and 7 to 7.5 kPa O_2 and 8.5 to 9 kPa CO_2 for copolymer amide-PE after 6 days at 0ºC (Escalona *et al.* 2007c). As it is well know most commodities require a minimum of 1 to 3 kPa O_2 to avoid anaerobic metabolism (Ke and Kader 1992). Therefore, OPP and copolymer amide-PE could be used to obtain optimal gas composition for minimally processed kohlrabi avoiding very low O_2 levels.

WEIGHT LOSS AND FIRMNESS

Kohlrabi stems with leaves kept under MAP in the range 0 to 10°C showed weight loss around 0.8 to 1.1%. The weight loss increased slightly to 1.2% when stems were kept in perforated bags (9 holes of 7 mm diameter per 100 cm^2). When the bags were transferred from chilling to a warmer temperature simulating a retail sale condition (i.e. 3 days at 10ºC), the increase in weight loss in MAP was lower than in perforated bags (Escalona *et al*. 2007a). In general, kohlrabi stems kept their firmness in MAP for 14 days at 0ºC, even after 3 days at 10ºC due to a very low dehydration found in these conditions. Additionally, firmness was reduced after 60 days at 0ºC followed by a retail sale period in comparison with that at harvest (Escalona *et al*. 2007b).

CHEMICAL ATTRIBUTES

Commonly soluble solids content (SSC) of kohlrabi stems ranged between 6.0 to 8.0 ºBrix. These levels were kept even after 30 days at 0ºC and an additional retail sale period in perforated bags, CA and MAP conditions. In the same trend, titratable acidity (TA) and pH showed minimal changes. This was due to the fact that the metabolic activity of kohlrabi stem is very low.

Kohlrabi slices also maintained the initial SSC and TA values after 14 days at 5°C in air and in CA (Escalona *et al.* 2006). However, minimally fresh processed kohlrabi dices kept 14 days at 0ºC showed significant decreases in SST and TA under MAP (Escalona *et al.* 2003).

SUGARS AND ORGANIC ACIDS CONTENTS

Kohlrabi stems commonly have about 0.4 to 1.7 g 100 mL^{-1} of sucrose and 1.9 to 2.1 and 1.9 to 2.5 g 100 mL^{-1} of fructose and glucose, respectively (Escalona *et al.* 2003, 2006, 2007a, 2007, 2007c). Souci *et al.* (2000) reported 1.1 g 100 mL^{-1} of sucrose, and 1.39 and 1.23 g 100 mL^{-1} of fructose and glucose, respectively in the edible portion of kohlrabi stems.

According to a previous report, fructose and glucose were commonly maintained under air and CA for 28 days at 0 or 5ºC. However under the same storage conditions sucrose content significantly declined, being lower under CA of 5 kPa O_2 plus 5 or 15 kPa CO_2 at 5ºC due to the reduction in the respiration rate (Escalona *et al.* 2006). Similar results were found in stems stored under MAP with low O_2 and high CO_2 (Escalona *et al.* 2007a). At the end of storage fructose and glucose contents can be kept probably due to the hydrolysis of sucrose. This hypothesis would explain the significant decline in sucrose compared to fructose and glucose throughout cold storage.

Kohlrabi slices had a similar trend in sugar changes within stems. After 14 days at 5ºC, slices showed fructose and glucose contents were maintained by the degradation of sucrose (Escalona *et al.* 2006). In contrast, diced kohlrabi stored for 14 days at 0°C showed a decrease in glucose, fructose and sucrose contents, probably due to their high respiration rate caused by the severity of cutting (Escalona *et al.* 2003). Therefore, changes in sucrose levels could be a good indicator of senescence and effect of CA on metabolic behaviour of kohlrabi.

In kohlrabi the main organic acid is citric (80 to 130 mg 100 mL^{-1} juice) with very small amounts of others organic acids like ascorbic, malic and maleic, in agreement with results reported by Souci *et al.* (2000). The effect of gas compositions on changes of organic acids has not been clear in kohlrabi stems. In general, a sharp reduction in citric acid succeeded during the retail sale period in humidified air (Escalona *et al.* 2007a). Other studies in plant tissues showed that atmospheres with low O_2 and/or high CO_2 retarded the decomposition of organic acids, although those results were inconsistent and sometimes contradictory (Ke *et al.* 1993).

MICROBIAL GROWTH

Fresh-cut vegetables can provide ideal conditions for the growth of microorganisms due to a low acid content in most of them (the pH commonly ranged from 5.8 to 6.0), wounding by the effect of cutting and high humidity inside the packages (Brackett 1987). In general, the initial average in aerobic microbial like mesophilic and psychrophilic bacteria counts found in kohlrabi slices was of 3.3 to 3.4 log cfu g^{-1} (**Fig. 2**). Those microbial counts increased to 4.3 to 5.6 log cfu g^{-1} after 14 days at 5ºC in air as well as under CA (Escalona *et al.* 2006). Nguyen-The and Carlin (1994) reported mesophilic bacteria counts in minimally processed vegetables from 3 to 6 log cfu g^{-1} after processing and from 3 to 9 log cfu g^{-1} after commercial cold storage. Kohlrabi cut in dices and stored 14 days at 0°C in MAP of 6 to 13 kPa O_2 plus 8 to 14 kPa CO_2 decreased mesophilic counts by 2 log cfu^{-1} compared to air (Escalona *et al.* 2003). In minimally processed kohlrabi, the yeast and mould growth was low, below 2 log cfu g^{-1} even after 14 days at 0 or 5ºC (Escalona *et al.* 2003, 2006).

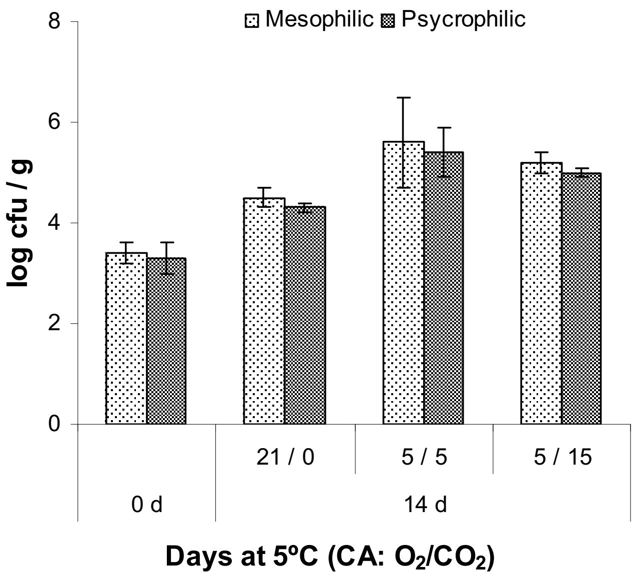

Fig. 2 Microbial counts (log cfu g^{-1} ± SE) in kohlrabi slices at day 0 and after 14 days at 5ºC in different atmospheres (kPa O_2 / kPa CO_2). Means (n = 3) ± SE.

PHYSIOLOGICAL DISORDERS AND POSTHARVEST PATHOLOGY

Kohlrabi stems stored at 0ºC for 60 days showed no chilling sensitivity in agreement with Hardenburg *et al.* (2004). However after three weeks at 0ºC, stems kept in perforated bags showed yellowing of stalk pieces and their senescence (Escalona *et al.* 2007a). An increased degreening severely affected the appearance of stems after 60 days in air at 0ºC (Escalona *et al.* 2007b). This physiological disorder was less important under MAP and CA.

On the other hand, kohlrabi stems developed bacterial soft rot caused by *Erwinia* sp. and *Pseudomonas* sp. when they were stored 60 days at 0°C in perforated bags (Escalona *et al.* 2007a). Hardenburg *et al.* (2004) also reported that kohlrabi stems are severely damaged by bacterial soft (*Erwinia carotovora* and *Pseudomona* spp.) and black rot (*Xanthomonas* spp.). MAP and CA delayed decay development due to the inhibitory effect of CO_2 at levels higher than 10 kPa on microbial growth (Kader *et al.* 1989). From our results, kohlrabi stems without leaves could not be stored for more than 2 months at 0ºC in air and high RH. This storage period is shorter than the 3 months at 0ºC and 98% RH reported by Hardenburg *et al.* (2004).

A disorder such as white blush affected severely the appearance and freshness of kohlrabi slices. This whitish colour was only slightly delayed by CA of 5 kPa O_2 + 15 kPa CO_2. The cause of white blush in kohlrabi slices was unclear.

CONCLUSION

The use of CA and MAP techniques delayed the metabolic activity of kohlrabi at low temperatures. Under these conditions the weight losses and decay development were also reduced. The gas composition of 2 to 5 kPa O_2 plus 5 to 20 kPa CO_2 was able to maintain the fresh quality of the intact stems and minimally fresh processed kohlrabi. A prolonged storage period of 30 and 60 days could be interesting for the transportation of kohlrabi stems, their distribution and retail sale at cold temperature near 0ºC. This is important taking into consideration that kohlrabi could be exported from

Europe to far markets by refrigerated maritime shipment. In addition, a long storage period could assure a continuous provision of fresh intact kohlrabi to the minimal fresh processing industry. Finally, different kind of cut such as slices, dices and sticks seems to be attractive and required by consumers.

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