PAPER

POLYETHYLENE FILM PACKAGING AFFECTS QUALITY OF "LISBON" LEMONS DURING LONG-TERM STORAGE

EFFETTO DEL CONFEZIONAMENTO CON FILM DI POLIETILENE SULLA QUALITA' DEI LIMONI "LISBON" DURANTE LA CONSERVAZIONE

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ABSTRACT

"Lisbon" lemons were divided into groups that were coated, packaged in polyethylene bags with or without a pouch containing KOH, or left unpackaged and uncoated. They were then stored at 8°C for up to 15 weeks. Packaging significantly reduced weight loss and fruit maintained a fresh appearance. Fruit in bags without KOH showed the highest incidence of decay. KOH moisture-absorbing capability significantly decreased rot during 5 weeks of storage plus one week of shelf-life, when compared to packaged fruit without KOH. No signs of chilling injury

RIASSUNTO

Frutti di limone "Lisbon" sono stati suddivisi in quattro gruppi e quindi immersi in una sospensione contenente un "edible coating", o confezionati in buste di film plastico contenenti o meno una data quantità di KOH. I frutti non trattati costituivano il testimone. Successivamente i frutti sono stati conservati per 5, 10 e 15 settimane a 8°C, nonché per una settimana di shelf-life a 20°C dopo ognuno dei tre periodi. Il confezionamento ha diminuito significativamente la perdita di peso e ha contribuito nel mantenere la freschezza dei frutti. I confezionamenti senza l'aggiun-

- Key word: chilling injury, *Citrus limon* Burm., decay, long-term storage, low-density polyethylene packaging, plastic bags, weight loss. -

were detected in any treatment. Packaged fruit without KOH revealed the highest concentration of ethanol and acetaldehyde in the juice.

ta del KOH hanno causato la più alta percentuale dei marciumi; infatti, la capacità del KOH di assorbire l'acqua si è rivelata determinante nella riduzione dei marciumi all'interno delle buste sino alla shelf-life successiva a 5 settimane di conservazione rispetto ai confezionamenti in cui non era presente il KOH. Nessun segno di danno da freddo è stato rilevato. I frutti confezionati avevano il più alto contenuto di acetaldeide ed etanolo nel succo.

INTRODUCTION

When subjected to temperatures lower than 13°C, lemons (*Citrus limon* Burm.) may undergo chilling injury (CI), mainly in the form of brown spots on the peel (pitting), causing mould development and brown to black areas on the membranes or carpellary walls (membranous stain). Storage temperatures lower than 13°C associated with a lack of ventilation in the refrigeration room can exacerbate other physiological disorders such as peteca and albedo browning (CALERO et al., 1981). Since temperatures higher than 13°C may lead to a high incidence of rot, increased weight loss and rapid senescence, investigations on alternative methods to prolong the storage life of lemons need to be made. COHEN and SCHIFFMANN-NADEL (1978) found that "the more mature the fruit was at the picking time, the less susceptible it was to pitting caused by CI at low temperatures". In fact, they observed that lemons at the yellow-green stage stored for 20 weeks at 8°C showed negligible CI and rot when compared to those stored at 14°C.

Attempts to preserve the fresh quality of various crops during storage have been made with beneficial effects both by wrapping with plastic films (KADER et al., 1989; SHAMAILA et al., 1992; BARTH et al., 1993) and waxing, particularly with the recently tested edible coating materials (KESTER and FENNEMA, 1986; NISPEROS-CARRIEDO et al., 1991; LAU and MEHERIUK, 1994). Polyethylene shrink film wrap reduced weight loss and pitting in grapefruit (PURVIS, 1985), lemon (SOZZI et al., 1983), cactus pear (PIGA et al., 1996a) and other crops (WANG, 1993). Despite the indubitable advantages of these techniques, unexpected effects can show up, such as mould invasion caused by a high relative humidity (RH) within the package or between the coating and the fruit, and off-odour development due to a shift in fermentative metabolism resulting in ethanol and acetaldehyde accumulation in the juice (as a consequence of inappropriate O_2 and CO_2 concentrations developing between fruit and packaging). The use of KOH to delay deterioration by trapping excess CO_2 would seem to compete with the fruit for ethanol absorption as observed by KELLY and SALTVEIT (1988). Moreover, KOH can absorb moisture. Pathogenic growth can be easily controlled by the application of postharvest fungicides (thiabendazole, imazalil), but recently, the market demand for pesticide free crops has led to a severe restriction in the use of these chemicals.

With concern for the public good in mind (aimed to prolong the postharvest life of lemons as long as possible), we studied the feasibility of using either an edible coating or a plastic bag made of low-density polyethylene film (LDPE), a material with high permeability to non-condensing gases and low transmission rate of water vapour, in order to preserve the quality of late-season lemons during relatively long-term storage and consequently to extend the marketing period until September, at a temperature regime below the CI threshold.

MATERIALS AND METHODS

Packaging, coating and storage

Completely yellow "Lisbon" lemons were harvested at the end of May. They were selected on the basis of uniform colour, size (150-180 g) and lack of physical damage and were randomly allotted to be coated, packaged in bags or left unpackaged to be used as controls. A fourth lot was packaged in bags provided with 1 gauze pouch containing 25 g of KOH per kg of lemon to reduce humidity and to check for a possible reduction of ethanol in the fruit juice. Coating was achieved by dipping the fruit in a 10% water solution of Semperfresh(®)FLO, a mixture of sucrose esters of fatty acids, sodium carboxymethylcellulose and food approved anti-foaming agent.

The dipping was performed at 20°C for 20 sec, then the fruit was allowed to dry at ambient temperature before storage. Fruit to be packaged was put on polystyrene trays, 6 fruits per tray, and sealed in LDPE bags (15 x 50 cm) made in our laboratory using a 50 µm thick LDPE film. The film was provided by GOGLIO L., Milano and its permeability to oxygen and carbon dioxide, measured using a GPM 200 instrument (G. Lyssy, Zollikon CH),was 5200 and 25000 cm^3 m^{-2} day^{-1} bar^{-1}, respectively. The water vapour transmission rate of the film, measured using an L80-4000 instrument (G. Lyssy, Zollikon CH) was 3.5 g m^{-2} day^{-1} in tropical conditions (90% RH and 38°C).

The bags were sealed using a GANDUS® GCMmatic impulse sealing machine. Each lot was then divided into 6 sublots corresponding to 3 storage plus 3 shelf-life periods; each sublot consisted of 3 replicates of 48 fruits. Fruit was then stored at 8°C and at 95% RH for 5, 10 and 15 weeks. To simulate market conditions, a week of shelf-life following each storage period was provided by simply transferring the fruit of each lot to 20°C and 75% RH, without removing the plastic bag from the packaged fruit.

Weight loss

The weight of each fruit was periodically recorded with an accuracy of ±0.01 g and weight losses are reported as percentage.

Sensory evaluation

At the end of each cold storage and shelf-life period, fruits were examined for incidence of decay and sensory evaluation was conducted on 60 undecayed fruits, taken at random, by 5 panelists who ranked the overall appearance using a scale from 1 to 5, with 1= very aged, 2=aged, 3=acceptable (limit of marketability), 4=fresh, 5=very fresh (fruit at harvest). The panelists were also asked to evaluate the fruit for the presence of off-flavour on a scale from 1 to 10 and to express their preference among treatments.

Chemical and physiological analysis

Three replicates of 10 fruits each were used to measure pH, titratable acidity (as per cent of citric acid) and total soluble solids (TSS) as °Brix of centrifuged juice of squeezed pulp.

Endogenous ethanol and acetaldehyde were determined in the headspace by flame ionization detection (FID) gas chromatography, comparing peak areas with those of external prepared standards as reported by DAVIS and CHACE (1969).

Juice (10 mL) from each replicate was transferred into 50 mL conical flasks secured with rubber serum caps; juice and standard samples were incubated in a shaking bath at 100 rpm for 20 min; volatiles were detected by withdrawing 2 mL of gas from the headspace and injecting it into a Varian 3300 GC (Varian, Walnut Creek - California) equipped with a 2 m x 2 mm glass column packed with 6.6% Carbowax 20M on 80/120 Carbograph 1 AW (running conditions were: N_2 carrier gas at 20 mL/min, injector 110°C, oven temperature 80°C, detector at 200°C).

Exogenous CO_2 and C_2H_4 in the headspace of 1-liter glass jars fitted with rubber septums, in which 10 fruits were individually placed for 1 hour at 20°C, were determined by thermal conductivity detector (TCD) and FID gas chromatography as previously reported (PIGA et al., 1996b). The CO_2 concentration in the bags of packaged fruits (with and without KOH) was measured by TCD gas chromatography and reported as percentage in volume.

Data analysis

Data were analysed for each period with MSTAT-C software (Michigan State University, 1991) by one-way analysis of variance.

To compare the evolution of physiological parameters (respiration rate and exogenous ethylene) during storage, a 4x6 completely randomized factor design was used, where treatments and storage periods were the factors. Means were separated by Duncan's multiple range test either at the 5 or 1% level of significance.

RESULTS AND DISCUSSION

Weight loss

Weight loss was significantly lower throughout all storage and shelf-life periods in packaged fruit when compared to coated and unpackaged fruit (Fig. 1). With the exception of the first storage period, the water absorbing capacity of KOH resulted in a significantly higher weight loss which was two to six times greater than that recorded for fruits packaged without KOH. In accordance with COHEN et al. (1990) and as expected, weight loss increased during storage and, after 15 weeks of storage plus 1 week of shelf-life, fruit that was unpackaged, coated, packaged and packaged with KOH lost 23.2, 15.3, 2.1 and 7.6% of the original weight, respectively. As expected, fruit of all lots lost more weight at the end of the shelf-life periods than at the of the corresponding previous storage period. Semperfresh application reduced weight loss with respect to noncoated fruit as previously observed for mandarins (EL-OTMANI et al., 1995), satsumas (D'AQUINO et al., 1996) and apples (KOKSAL et al., 1994), but this reduction was only significant at the end of the shelf-life periods following 10 and 15 weeks of storage. This can be explained by the particular pathway in which water probably moves through the fruit surface. In fact, BURG and BURG (1965) postulated that water transport probably occurs in a liquid aqueous phase in the cuticle, in which a 10^4 fold lower diffusivity of vapour occurs. BEN-YEHOSHUA et al. (1985) observed that waxing increased resistance of oranges and grapefruit to water evaporation by only 25%. Thus, since the surface coating itself has many pits and cracks, it affects water loss very little.

Sensory evaluation

The analysis of overall appearance conducted after each storage and shelf-

life period revealed a higher score for packaged fruit, with or without the KOH pouch, than for coated and unpackaged fruit, whereas no statistically significant differences were observed within the two packaged lots and the two unpackaged ones (Fig. 2). It has to be noted that the average score of the two packaged lots was never below the limit of marketability (score of 3), while the average of the unpackaged fruit was always below the threshold, with the exception of the first storage period. Particularly, at the end of all storage periods, 35% of the unpackaged fruit and 30% of the coated fruit were rated as unmarketable versus 10% of the packaged fruit and 8% for packaged with KOH (data not shown). ALBRIGO and ISMAIL (1983) noted an impairment of the external appearance and, consequently of marketability of waxed citrus fruit, when weight loss was more than 5%. However, our findings show that fruit packaged in the presence of KOH had an overall good appearance even if weight loss exceeded 7%. Deterioration of citrus fruit is highly correlated with transpiration (BEN-YEHOSHUA, 1969). The ineffectiveness of Semperfresh in reducing moisture loss can probably

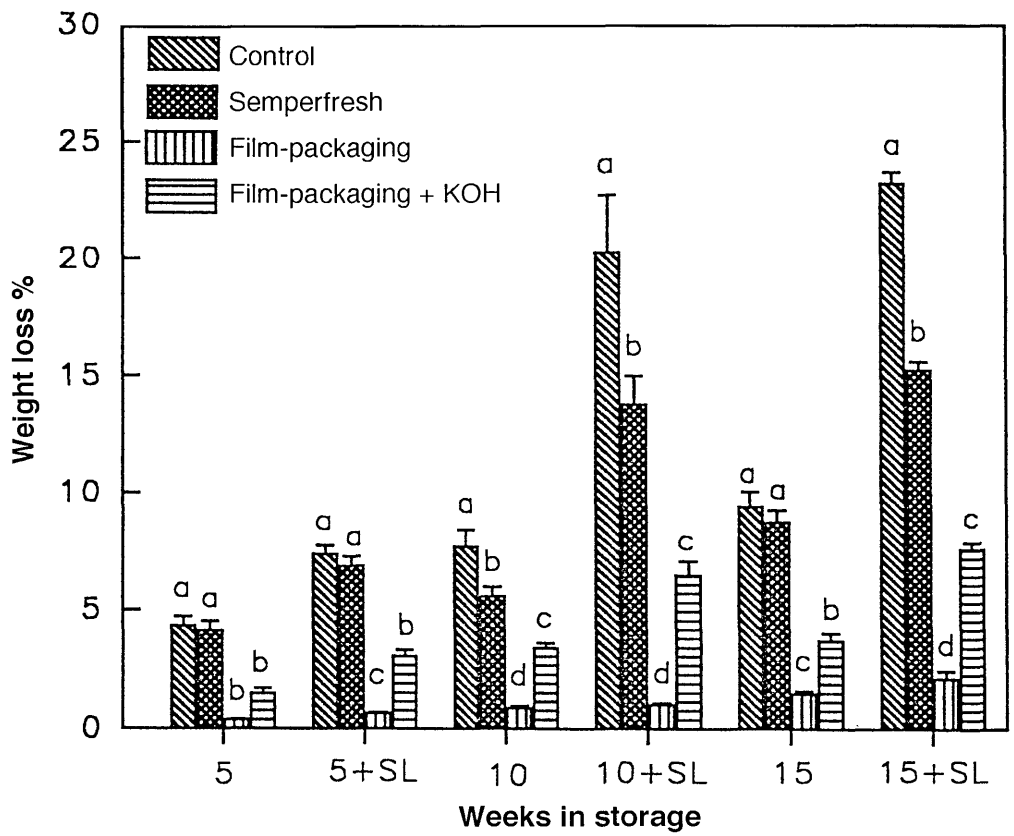

Fig. 1 - Influence of Semperfresh coating and film packaging with or without KOH on weight loss of "Lisbon" lemons after storage at 8°C and after transfer to shelf-life (SL) at 20°C. Average of 60 measurements + SE (vertical bars). Columns with different letters differ significantly at P<0.01.

explain its lack of beneficial influence on overall fruit appearance.

Despite the relatively low storage temperature, either external or internal signs of CI were not found in packaged and unpackaged fruit except for a very low incidence of peteca in packaged fruit. As already cited, the lower susceptibility of lemons to temperature inducing CI as a more mature stage is reached and the beneficial effect of a temperature higher than 15°C while the fruit is on the tree, may have acted as a conditioning treatment (HOUCK et al., 1990), thus preventing CI.

Decay

Packaged fruit always showed the highest incidence of rot, either at the end of the storage periods (5, 10 or 15 weeks) or the following shelf-life period of 1 week (Fig. 3). This can be surely attributed to the high RH in the bags that favoured mould development, as previously observed for other products (GRIERSON, 1969; HARDENBURG, 1951; SCOTT et al., 1964). The fruit packaged with KOH showed less decay than those without it because KOH absorbs moisture. However, according to Duncan's test, the dif-

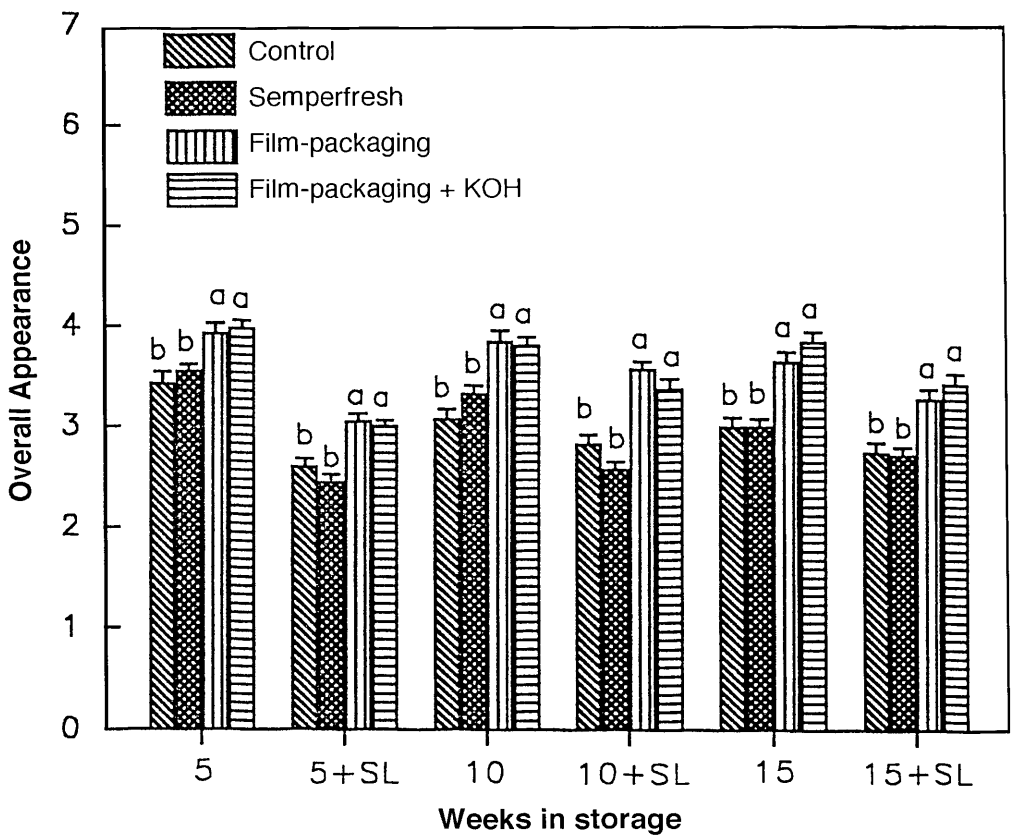

Fig. 2 - Change in visual overall appearance of "Lisbon" lemons coated with Semperfresh or film-packaged with or without KOH or left unpackaged and uncoated, after storage at 8°C and after transfer to shelf-life (SL) at 20°C. Data are the average of 60 measurements + SE (vertical bars). Columns with different letters differ significantly at $P<0.01$.

ferences were not always significant. There were no significant differences after the longest periods of storage (15 and 15+1 weeks) but, after the middle ones (10 and 10+1 weeks) there were significant differences between packaged fruit (with or without KOH) and the control and coated fruit. It is pointed out that the fruit did not receive any fungicide treatment. At the end of 15 weeks of refrigeration, when no differences in incidence of decay were observed among the lots probably due to an enhanced senescence of all the fruit, total decay was in the range of 40-50%. The prevailing pathogen was *Penicillium digitatum*, that accounted for 90% of total decay (data not showed).

Chemical and physiological analysis

Gas concentrations within the packages, averaged from normal atmospheric composition to 2.2. and 18.5%, respectively for CO_2 and O_2. Although KOH absorbed most of the CO_2 in the surrounding space, differences in CO_2 concentrations between fruit packaged with and without absorbent (Fig. 4), although significant, were too small to affect fruit physiology.

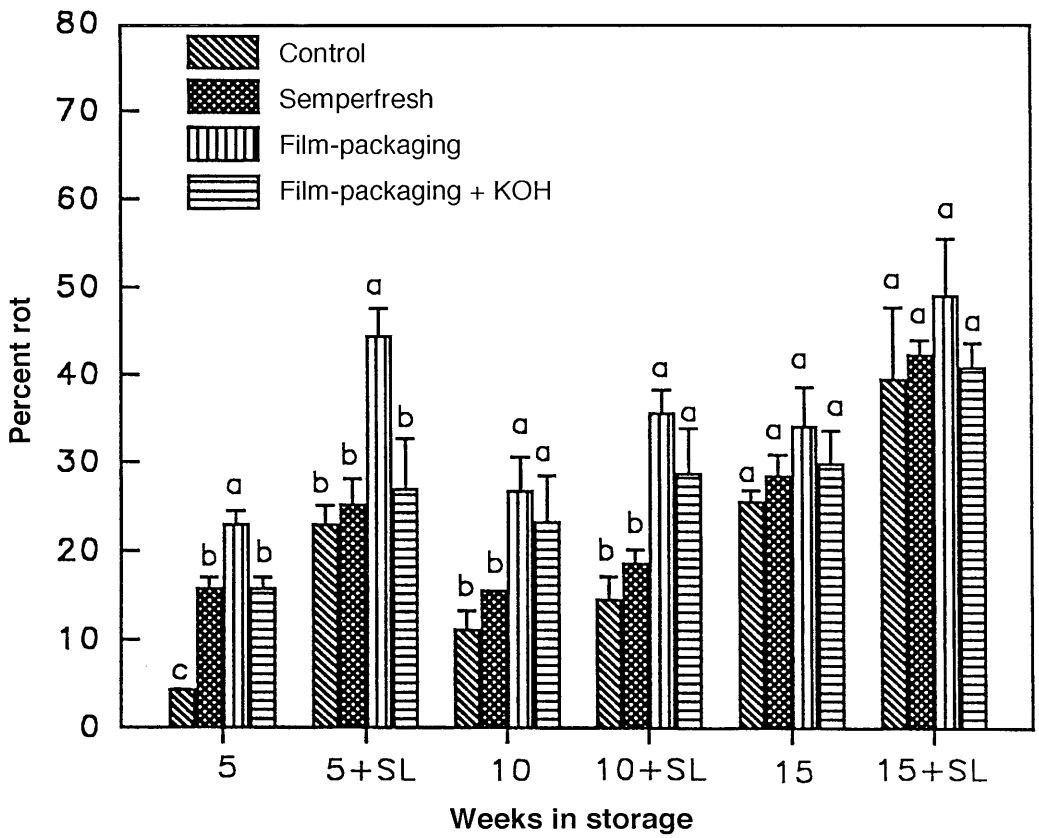

Fig. 3 - Incidence of decay (%) in "Lisbon" lemons coated with Semperfresh or film-packaged with or without KOH or left unpackaged and uncoated, after storage at 8°C and after transfer to shelf-life (SL) at 20°C. Data are the average of 3 replicates + SE (vertical bars).
Columns with different letters differ significantly at $P<0.05$.

The respiration rate of lemons was very low when compared to other citrus species. It was 6.44 mL kg^{-1} h^{-1} exogenous CO_2 evolved at harvest, while ethylene was scarcely detected. There were no significant differences among the treatments either at the end of the cold storage or at the end of the shelf-life periods both for exogenous carbon dioxide and ethylene (data not shown).

Internal quality parameters (pH, titratable acidity and TSS) underwent slight modifications, with no appreciable differences among treatments (Table 1). Acetaldehyde content in the juice was significantly higher in packaged fruit till removal from cold storage conditions, with respect to unpackaged ones. While ethanol concentration differed greatly in the packaged lot throughout the whole storage period with respect to the unpackaged ones, except for the shelf-life period which followed the 5-week storage period. Ethanol content was significantly lower in juice from packaged fruit with KOH than in juice from packaged fruit without KOH, thus probably confirming the competition for this volatile exerted by KOH as suggested by KELLY and SALTVEIT (1988). No differences were

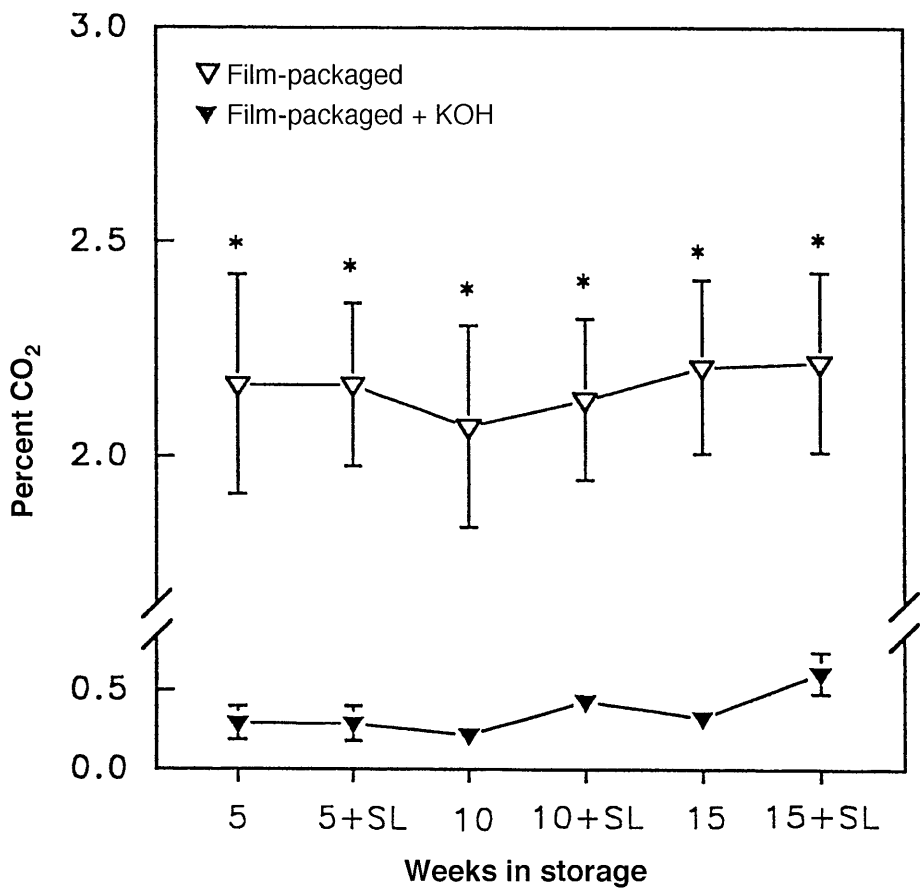

Fig. 4 - Accumulation of CO_2 (%) in low-density polyethylene bags with or without KOH, six "Lisbon" lemons per bag, during storage at 8°C and after transfer to shelf-life (SL) at 20°C. Data are the average of 5 replicates + SE (vertical bars). * Significantly different at $P<0.01$.

Table 1 - Chemical parameters of "Lisbon" lemons during storage and subsequent shelf-life (SL) periods.

Treatments	Storage period	pH	Acidity (% citric acid)	TSS (°Brix)	Acetaldehyde (µl/L)	Ethanol (µl/L)
	harvest	2.55	7.33	6.40	0.16	3.17
Control	5 Weeks	2.62[x]	5.65	5.97	0.14b	5.08b
Semperfresh	5 Weeks	2.61	5.62	5.80	0.12b	0.00b
Film -packaging	5 Weeks	2.63	5.74	6.63	0.70a	45.14a
Film-packaging + KOH	5 Weeks	2.63	5.76	5.97	0.43b	10.97b
Significance		ns	ns	ns	*	*
Control	5 Weeks + 1 wk of SL	2.63	5.51	5.70	0.34	4.97
Semperfresh	5 Weeks + 1 wk of SL	2.65	5.52	5.80	0.16	2.46
Film -packaging	5 Weeks + 1 wk of SL	2.67	5.63	6.27	0.20	14.92
Film-packaging + KOH	5 Weeks + 1 wk of SL	2.70	5.55	5.97	0.19	1.99
Significance		ns	ns	ns	ns	ns
Control	10 Weeks	2.71	5.14	5.73	0.13b	2.11b
Semperfresh	10 Weeks	2.70	5.33	5.67	0.07b	1.38b
Film -packaging	10 Weeks	2.69	5.47	5.97	1.15a	32.82a
Film-packaging + KOH	10 Weeks	2.72	5.20	5.23	0.53b	9.34b
Significance		ns	ns	ns	**	*
Control	10 Weeks + 1 wk of SL	2.75	5.10	5.63	0.25	6.33b
Semperfresh	10 Weeks + 1 wk of SL	2.74	5.10	5.13	0.13	4.07b
Film -packaging	10 Weeks + 1 wk of SL	2.70	5.25	6.07	0.18	16.12a
Film-packaging + KOH	10 Weeks + 1 wk of SL	2.75	5.15	5.37	0.23	8.48ab
Significance		ns	ns	ns	ns	**
Control	15 Weeks	2.75	5.08	5.53	0.11c	6.26b
Semperfresh	15 Weeks	2.77	5.22	5.20	0.09c	7.63b
Film -packaging	15 Weeks	2.74	5.14	5.55	1.72a	42.02a
Film-packaging + KOH	15 Weeks	2.78	5.09	5.55	0.74b	10.27b
Significance		ns	ns	ns	**	**
Control	15 Weeks + 1 wk of SL	2.78	5.15	5.40	0.16	9.93b
Semperfresh	15 Weeks + 1 wk of SL	2.81	5.25	5.05	0.13	10.32b
Film -packaging	15 Weeks + 1 wk of SL	2.80	5.17	5.35	0.22	19.45a
Film-packaging + KOH	15 Weeks + 1 wk of SL	2.83	5.14	5.45	0.20	8.72b
Significance		ns	ns	ns	ns	**

ns,*, **= non significant or significant at 5 or 1%, respectively.
x Values followed by the same letter in columns and for each storage period are not significantly different.

detected between the control and both coated fruit and packaged fruit without KOH. The expected trend of acetaldehyde and ethanol was seen only in unpackaged fruits. In fact, in this lot higher volatile concentrations were noticed at the end of each shelf-life period with respect to the corresponding previous storage period. This could be due to a more pronounced CI stress in

unpackaged fruit when compared to packaged ones, even if no visible symptoms of CI were observed in either lot. On the other hand, a decrease in volatile content in juice could be attributed to a drastic increase in film permeability to acetaldehyde and ethanol when bags were transferred from 8 to 20°C, which could have overcome the increase of volatile production. This could also be a result of the film barrier effect, as the atmospheric composition surrounding the packaged fruit would not have shifted respiratory metabolism from aerobic to anaerobic. Despite the high concentration of volatiles, off-flavour presence was not detected by sensory evaluation, and panelists did not have preferences for any of the treatments.

In conclusion the polyethylene film used in this trial allowed late harvested lemons to be stored at 8°C for long periods, maintaining a good overall appearance and minimising weight loss. The major problem was the high incidence of decay inside the bags. KOH within bags helped to reduce loss of produce due to rot, but not adequately. Moreover, it cannot be used for commercial purposes. Thus, further study is needed to find a plastic film with suitable water vapour permeability, that matches the reduction of weight loss and the control of decay spread, eliminating either the use of any moisture absorbing material or the traditional prestorage fungicide application.

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The authors contributed equally to this study.
Trade names are used in this paper solely to provide specific information.

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