EFFECTS OF POSTHARVEST TREATMENTS ON STORAGE QUALITY OF LIME (*CITRUS LATIFOLIA* TANAKA) FRUIT

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Abstract

Limes (*Citrus latifolia* Tanaka) are an attractive fruit crop but generally suffer a loss in value as their colour changes from green to yellow. Various approaches were taken to slow degreening including low temperature storage, use of controlled atmosphere (CA) environments, and treatment of fruit with physiologically active agents such as gibberellic acid (GA_3). However, the cold storage life of lime fruit can also be restricted by a number of factors including chilling injury (CI) and rots. Various pretreatments such as the use of fungicide (thiabendazole, TBZ) and hot water dipping (HWD) and several postharvest regimes based on temperature conditioning (step down technique) and intermittent warming (IW) regimes were further investigated to protect the fruit against rots and CI during cold storage. The objective of this study was to determine what storage conditions and pretreatments would permit long term storage of NZ limes with minimal loss of quality.

CA storage (10% O_2 with 0 or 3% CO_2) was compared to regular air storage (RA) and IW (varying durations) treatments across a range of temperatures. Although some CA storage regimes could assist in delaying degreening, none of the treatments provided protection against CI. CA storage at 3% CO_2 delayed yellowing and gave better fruit quality than the low CO_2 treatment. High CO_2 CA treatments at 5 or 7°C decreased the rate of colour change compared to other constant temperature treatments but did not protect against CI. CI limited storage of fruit under all conditions at constant low temperatures.

Including fungicide (TBZ) in the dip water reduced the incidence of rots and had a secondary effect on protection against CI of lime fruit. However, fungicide use may sometimes exacerbate stresses such as heat injury on lime peel. Hot water dipping has been shown previously to hold potential as a storage pretreatment, but this technique may give risk of damage on produce if it is dipped at too high a temperature. Some HWD treatments did delay degreening, but there was no major effect on CI. HWD at > 47°C for ≥ 4 min caused heat injury to NZ limes. All HWD treatments showed severe CI (>15%) after 10 weeks of cold storage; and HWD fruit stored under RA at 13°C did not

show any CI but showed some pitting (≤ 10%) and degreened rapidly. Overall no suitable HWD treatment for limes was identified in this trial.

This project identified the critical periods and temperature conditions for successful IW of limes. The IW conditions successfully delayed losses in quality of lime fruit provided the first warming period was applied within the first 20 days of storage. At least 2-cycle IW was required to maintain lime quality during long term storage. Some benefits were found after just one cycle of IW treatment but there were not enough to extend storage life.

IW storage benefited fruit quality and provided the highest overall fruit quality of all postharvest treatments tested. The degreening of lime during cold storage at 5°C could be delayed by IW treatments in which the fruit were stored at 5°C for 12, 16 or 20 days then moved to 15°C for 2 days. Both 2- and 6-cycle IW treatments proved satisfactory for maintaining colour on the green and yellow side of lime for 12 weeks of storage. IW treatments in which fruit were warmed within 20 day of cold storage did not show significant CI symptoms after 12 weeks of storage, and the 2-cycle IW treatment showed only a low percentage of CI fruit at this time. A 2-cycle IW treatment was almost as effective as 6 cycles, and a step down treatment also showed some promising results, indicating that it may be possible to further optimize the time and duration of variable temperature storage regimes to meet both quality requirements and the constraints of temperature management in commercial coolstores. The application of these regimes to other citrus species may also be beneficial. There are a number of physiological explanations that may account for the effectiveness of IW including positive effects on heat shock protein (HSP) and cell membranes. Nutritional factors such as vitamin C and flavonoid compositions were also investigated and fruit that did not show visible CI were found to retain at-harvest levels of these factors. Practical ways of implementing IW are discussed.

In order to understand the effectiveness of IW on degreening, I used a logistic model to describe degreening of lime peel. This modelling approach demonstrated that IW did not change the mechanism of lime degreening based on the similarity between the hue values predicted by the model and the actual hue values measured during lime storage. The activation energy (E_a) for degreening based on either hue angle (H°) or colour score (CS) during air storage was estimated to be ~53 and ~86 $KJ.mol^{-1}$, respectively. Relationship between colour (H° and CS) and chlorophyll content, relationship between reflectance spectra (%), chlorophyll content and H° of lime fruit stored under different conditions are presented and discussed. This data allowed deduction to be made about the changes in individual pigments that are driving colour change during “good” and “bad” storage.

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Abbreviations

a*	CIE Lab 'a' value measured by a colorimeter
ABA	abscisic acid
ACC	1-aminocyclopropane carboxylic acid
ANOVA	analysis of variance
APX	ascorbate peroxidase
b*	CIE Lab 'b' value measured by a colorimeter
°C	degrees Celsius
CAT	catalase
cm	centimetre
C_2H_4	ethylene
$C_{20}H_{39}$	phytol
C*	chroma
CA	controlled atmosphere
C_a	chlorophyll *a*
C_b	chlorophyll *b*
C_{x+c}	carotenoids
CF	compression firmness
d	day
PFR	Plant and Food Research
CI	chilling injury
CO_2	carbon dioxide
CS	colour score
DNA	deoxyribonucleic acid
DSM	diosmin
e	exponential
E_a	activation energy
EB	extraction buffer
Eq.	equation
ERC	eriocitrin
°F	degrees Fahrenheit

FC	fluorescent compound
FW	fresh weight
GA_3	gibberellic acid
GAs	gibberellins
GC	gas chromatography
GR	glutathione reductase
hr	hour
H°	hue angle
$H°_C$	$H°_{CR200}$ (hue angle measured by chromameter CR200)
$H°_S$	$H°_{Spectrophotometer}$ (hue angle measured by spectrophotometer CM-2600d)
$H-\infty$	maximum hue
$H+\infty$	minimum hue
H1	Harvest 1
H2	Harvest 2
H3	Harvest 3
H4	Harvest 4
H5	Harvest 5
HI	heat injury
HPLC	high performance liquid chromatography
HSP	hesperidin
HWD	hot water dipping
HWRB	hot water rinsing and brushing
IRF	isorhoifolin
IW	intermittent warming
J	Joule
K	degrees Kelvin
k	reaction rate constant
k_0	preexponential Arrhenius constant ($time^{-1}$)
kD	kiloDaltons
kg	kilogram
kJ	kiloJoule
KOAc	potassium acetate
L*	Lightness measured by a colorimeter

l	litre
LCMS	liquid chromatography mass spectrometry
LSD	least significant difference
MA	modified atmosphere
MAV	measurement area value
MeOH	methanol
MET	methionine
Mg^{2+}	magnesium ion
mm	millimetre
min	minute
mol	mole
µg	microgram
mg	milligram
µl	microlitre
ml	millilitre
n.d.	no data
nl	nanolitre
nm	nanometre
NPO	neoponcirin
NRG	naringin
NRT	narirutin
O_2	oxygen
PAs	polyamines
PCA	principal components analysis
PC1	principal component 1
PC2	principal component 2
PGRs	plant growth regulators
ppm	parts per million
Put	putrescine
R	the universal gas constant
R^2	R-squared value
R800	reflectance at 800 nm
R700	reflectance at 700 nm

R680	reflectance at 680 nm
R520	reflectance at 520 nm
R480	reflectance at 480 nm
RA	regular air
RH	relative humidity
RNA	ribonucleic acid
ROS	reactive oxygen species
RP	rusty pigment
RTN	rutin
rpm	revolutions per minute
s	second
SAM	S-adenosylmethionine
SAM dec.	S-adenosylmethionine decarboxylase
SCE	spectral component excluded
SCI	spectral component included
SE	standard error
SOD	superoxide dismutase
Spd	spermidine
Spm	spermine
SSC	soluble solids content or Brix°
t	time
t_0	reference time at day 0
t_{ref}	reference time (d)
T	temperature (Kelvin)
TA	titratable acidity
TBZ	thiabendazole
TC	temperature conditioning
UV	ultra violet light