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Fresh and processed apple products: vacuum infiltration, texture and quality

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Abstract

Apple slice texture and quality is affected by a diverse array of preharvest, postharvest and processing factors. The study described in this thesis had two primary objectives:

1) to investigate factors that influence the effectiveness of the vacuum infiltration process and thereby identify ways to enhance infiltration in difficult-to-infiltrate fruit.
2) to ascertain the effects of a range of pre- and post- harvest factors including cultivar, temperature, edible surface coatings and calcium treatments on fresh and processed apple texture and quality.

Vacuum infiltration is used to replace the 8-36% of tissue volume made up by occluded gases in the commercial production of solid-pack canned apple slices. This removal: reduces textural degradation caused by thermal expansion of these gases; prevents can corrosion and off-flavour development caused by residual oxygen; and ensures that relative density of the tissue is increased sufficiently to achieve prescribed can fill weights. Vacuum infiltration is often incomplete for fruit produced in cold growing seasons and also with immature fruit. In this study, level of infiltration achieved in apple slices was affected by pre-condition of the tissue (eg. maturity, porosity, whole fruit density) and by variables that relate directly to the vacuum infiltration process (eg. vacuum time, absorption time, solution temperature). Infiltration was enhanced in fruit taken from later harvests and in fruit pre-stored for a short period at 20 °C. Key aspects of the vacuum infiltration process were investigated and the relationships between vacuum time, absorption time, and slice relative density were characterised. Reduced vacuum levels were detrimental to liquid impregnation. To maximise infiltration in 'Braeburn' fruit required: high vacuum levels (preferably > 95 kPa), vacuum times of approx 2 min, and absorption times $\geq$ 6 min. Infiltration was enhanced by heating the infiltrating solution.

The texture and quality of solid-pack canned apple slices is to a large extent determined by the quality of the raw product. 'Braeburn', 'Fuji' and 'Granny Smith' apples varied quite markedly in terms of textural quality, storage potential, tolerance of ambient temperatures and ultimately in their response to processing. In general, fresh and processed apple texture declined with increasing fresh fruit storage temperature and duration. Application of edible surface coatings enhanced texture and reduced free-juice content of canned slices. The level of benefit achieved varied considerably with cultivar and storage temperature and, to a more limited extent, grower line and coating concentration. Calcium application during the pre- or post-harvest phases had little effect on processed slice texture, but in some cases free-juice volume was reduced. The interrelationships between the variables under study are discussed and a conceptual model presented that describes the effects of key postharvest variables on fresh and processed fruit texture.

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List of Abbreviations

a	radius of twist tester blade (m)
a_o	radius of twist tester spindle
A	fruit surface area (m^2)
A^{punch}	area of punch/penetrometer probe
ACP	anaerobic compensation point
ANOVA	analysis of variance
ATP	adenosine triphosphate
b	width of twist tester blade
BC	background colour
BKra	maximum force as measured by Kramer shear cell (blanched fruit slices; N)
c, d, g, h, i, j, k, l, m, n, o, q, s, u, v	parameters for linear and non-linear equations
C	chroma
CA	controlled atmosphere storage
CI	confidence interval
CMC	carboxymethylcellulose, sodium salt
cont	control
CV	coefficient of variation
HD	harvest date
Δp_j	difference in partial pressure of gas j between internal and external atmospheres (Pa)
Δp_{H_2O}	water vapour pressure difference between fruit and surrounding airstream
Δp_{O_2}	difference in partial pressure of oxygen between internal and external atmospheres (Pa)
$\Delta \rho^{slice}_{rel}$	change in relative density of an apple slice after infiltration
DOI	degree of infiltration (%)
DPen	firmness as measured by drill-mounted penetrometer (N)
ε	cortical tissue porosity (m^3.m^{-3})
ε^a	cortical tissue porosity estimated using infiltration (m^3.m^{-3})
ε^b	cortical tissue porosity estimated from initial relative density of tissue and juice (m^3.m^{-3})
ε_e	effective porosity
EP	extinction point
Eq(s).	equation(s)
f	resonance frequency
f	fruit firmness
F	bioyield point
FCP	free choice profiling
Fig(s).	figure(s)
FKra	maximum force as measured by Kramer shear cell (fresh fruit slices; N)
FT	fermentation threshold
g	gravity constant 9.8 m.s^{-2}

θ	angle of rotation (°)
HDM	hydrodynamic mechanism
IAS	intercellular air space
IPen	firmness as measured by Instron operated penetrometer (N)
K_c	commodity compression coefficient
K_{FT}	firmness temperature coefficient (%/°C)
K_s	commodity shear coefficient
L	lightness
LO	low oxygen storage
LOI	level of infiltration
LOL	lower oxygen limit (kPa)
LOL^i	internal lower oxygen limit (kPa)
LTLT	low temperature long time blanch treatment
m_T	moment
M	mass
M^{fruit}	fruit mass (kg)
M^{app}	apparent mass of non-infiltrated slice in air (kg)
MA	modified atmosphere storage
M_i^{app}	apparent mass of infiltrated slice submerged in water (kg)
M_n^{app}	apparent mass of non-infiltrated slice submerged in water (kg)
M_w^{app}	apparent mass of slice submerged in water (kg)
NS	not significant
P	probability or level of significance of a statistical test
p^{punch}	perimeter of punch
PD	permanent deformation (mm)
pH	concentration of hydrogen ions in a solution
p_{atm}	atmospheric pressure
p_c	capillary pressure
p_j^e	partial pressure of gas *j* in the external atmosphere (Pa)
p^e_{O2}	external partial pressure of oxygen (kPa)
p^i_{CO2}	internal partial pressure of carbon dioxide (kPa)
p_j^i	partial pressure of gas *j* in the internal atmosphere (Pa)
p^i_{O2}	internal partial pressure of oxygen (kPa)
p_r	reduced capillary pressure
p_{vac}	pressure during vacuum treatment
P'_{H2O}	fruit skin permeance to water vapour (mol.s^{-1}.m^{-2}.Pa^{-1})
P_j	permeability to gas *j* (mol.s^{-1}.m.m^{-2}.Pa^{-1})
P'_j	permeance to gas *j* (mol.s^{-1}.m^{-2}.Pa^{-1})
$P'^{\mathrm{skin}}_{\mathrm{O2}}$	fruit skin permeance to oxygen (mol.s^{-1}.m^{-2}.Pa^{-1})
$P'^{\mathrm{coat}}_{\mathrm{O2}}$	coating permeance to oxygen (mol.s^{-1}.m^{-2}.Pa^{-1})
PCA	principal component analysis
PGA	polygalacturonic acid
PE	pectinesterase
PG	polygalacturonase
PI	prediction interval
PKra	maximum force as measured by Kramer shear cell (processed fruit slices, N)
σ	crush strength (Pa)

Q_{10}	temperature coefficient (=[rate of O_2 uptake at (T+10°C)]/[rate of O_2 uptake at T])
QDA	quantitative descriptive analysis
R	apparent compression ratio
r	actual compression ratio
r^2	square of the correlation coefficient (r) or the proportion of total variation in y that can be explained by the independent variable x
$r^T_{O_2}$	specific rate of transfer of O_2 at temperature T (mol.s^{-1})
RH	relative humidity
RG 1	rhamnogalacturonan 1
RQ	respiratory quotient
RQB	respiratory quotient breakpoint
ρ_{H_2O}	density of water (kg.m^{-3})
ρ^{fruit}_{rel}	density of whole fruit relative to water
ρ^{juice}_{rel}	density of juice relative to water
$\rho^{slice}_{rel,\ init}$	density of an uninfiltrated slice relative to water
ρ^{slice}_{rel}	density of a slice relative to water
SE	standard error
SED	standard error of the difference between means
SEM	standard error of the mean
SI	starch index
SPE	sucrose polyester formulation
SS	total soluble solids content (%, ° Brix)
t	time
T	temperature (°C)
TBio	twist test bioyield (kPa)
TCA	tricarboxylic acid cycle or Krebs cycle
TMax	twist test maximum crush strength (kPa)
TPA	texture profile analysis
V	volume
V_h	volume of submerged portion of hook (m^3)
V_s	volume of slice (m^3)
WVP	water vapour pressure
WVPD	water vapour pressure deficit
XET	xyloglucan endotranslycosylase
x	volumetric fraction of liquid
x_v	volume fraction of pore occupied by liquid
WSP	water-soluble polyuronides
Z	distance of the centre of mass of the rod from the axis of rotation