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

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Suzie Marie Newman
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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 ≥ 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)
- $a_r$: 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
- $\Delta p_j$: difference in partial pressure of gas $j$ between internal and external atmospheres (Pa)
- $\Delta p_{H_2O}$: water vapour pressure difference between fruit and surrounding airstream
- $\Delta p_{O_2}$: difference in partial pressure of oxygen between internal and external atmospheres (Pa)
- $\Delta p_{rel}^{slice}$: change in relative density of an apple slice after infiltration
- DOI: degree of infiltration (%)
- DPen: firmness as measured by drill-mounted penetrometer (N)
- $\varepsilon$: cortical tissue porosity ($m^3.m^{-3}$)
- $\varepsilon^a$: cortical tissue porosity estimated using infiltration ($m^3.m^{-3}$)
- $\varepsilon^b$: cortical tissue porosity estimated from initial relative density of tissue and juice ($m^3.m^{-3}$)
- $\varepsilon_e$: 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)
Kc  commodity compression coefficient
K_{FT}  firmness temperature coefficient (%/°C)
K_j  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)
LTLLT  low temperature long time blanch treatment
m_{\tau}  moment
M  mass
M_{fruit}  fruit mass (kg)
M_{\text{app}}  apparent mass of non-infiltrated slice in air (kg)
MA  modified atmosphere storage
M_{\text{app}}  apparent mass of infiltrated slice submerged in water (kg)
M_{\text{app}}  apparent mass of non-infiltrated slice submerged in water (kg)
M_{\text{app}}  apparent mass of slice submerged in water (kg)
NS  not significant
P  probability or level of significance of a statistical test
P_{\text{punch}}  perimeter of punch
PD  permanent deformation (mm)
pH  concentration of hydrogen ions in a solution
P_{\text{atm}}  atmospheric pressure
p_c  capillary pressure
p_{j}  partial pressure of gas j in the external atmosphere (Pa)
p_{j}^{\text{O}_2}  external partial pressure of oxygen (kPa)
p_{j}^{\text{CO}_2}  internal partial pressure of carbon dioxide (kPa)
p_{j}  partial pressure of gas j in the internal atmosphere (Pa)
p_{j}^{\text{O}_2}  internal partial pressure of oxygen (kPa)
p_r  reduced capillary pressure
P_{\text{vac}}  pressure during vacuum treatment
P_{\text{H}_2\text{O}}^{\text{skin}}  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}^{\text{skin}}  permeance to gas j (mol.s^{-1}.m^{2}.Pa^{-1})
P_{\text{O}_2}^{\text{skin}}  fruit skin permeance to oxygen (mol.s^{-1}.m^{-2}.Pa^{-1})
P_{\text{O}_2}^{\text{coat}}  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)
temperature coefficient (=rate of $O_2$ uptake at $(T+10^\circ C)$)/[rate of $O_2$ uptake at $T$])

QDAquantitative 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 $x$

$\dot{r}_{O_2}^T$specific rate of transfer of $O_2$ at temperature $T$ (mol.s$^{-1}$)

RHrelative humidity

RG 1rhamnogalacturonan 1

RQrespiratory quotient

RQBrrespiratory quotient breakpoint

$\rho_{w}$density of water (kg.m$^{-3}$)

$\rho_{rel}$density of whole fruit relative to water

$\rho_{juice}$density of juice relative to water

$\rho_{slice}$density of an uninfiltrated slice relative to water

$\rho_{slice, ini}$density of a slice relative to water

$\sigma$standard error

SEDstandard error of the difference between means

SEMstandard error of the mean

SIstarch index

SPEsucrose polyester formulation

SStotal soluble solids content ($\%$, °Brix)

$t$time

$T$temperature ($^\circ$C)

TBio twist test bioyield (kPa)

TCAtricarboxylic acid cycle or Krebs cycle

TMaxtwist test maximum crush strength (kPa)

TPAtexture profile analysis

$V$volume

$V_h$volume of submerged portion of hook (m$^3$)

$V_s$volume of slice (m$^3$)

WVPwater vapour pressure

WVPDwater vapour pressure deficit

XETxyloglucan endotransglycosylase

$x$volumetric fraction of liquid

$x_v$volume fraction of pore occupied by liquid

WSPwater-soluble polyuronides

$Z$distance of the centre of mass of the rod from the axis of rotation