UNIVERSIDAD DE CÓRDOBA y UNIVERSITÀ DI FOGGIA

E.T.S. DE INGENIERÍA AGRONÓMICA Y DE MONTES

FACOLTÀ DI AGRARIA

DEPARTAMENTO DE BROMATOLOGÍA Y TECNOLOGÍA DE LOS ALIMENTOS

DIPARTIMENTO DI SCIENZE AGRARIE, DEGLI ALIMENTI E DELL'AMBIENTE

"*Estrategias dirigidas a retrasar el pardeamiento enzimático en productos destinados a la IV Gama: alcachofas y patatas*"

TESIS DOCTORAL

Ana Belén Cabezas Serrano

Directores:

Profª. Mª Teresa Sánchez Pineda de las Infantas
Prof. Giancarlo Colelli

2013

TITULO: *Estrategias dirigidas a retrasar el pardeamiento enzimático en productos destinados a la IV gama: alcachofas y patatas*

AUTOR: *ANA BELEN CABEZAS SERRANO*

© Edita: Servicio de Publicaciones de la Universidad de Córdoba.
Campus de Rabanales
Ctra. Nacional IV, Km. 396 A
14071 Córdoba

www.uco.es/publicaciones
publicaciones@uco.es

UNIVERSIDAD
D
CÓRDOBA

Departamento de Bromatología
y Tecnología de los Alimentos

"Estrategias dirigidas a retrasar el pardeamiento enzimático en productos destinados a la IV Gama: alcachofas y patatas"

TESIS

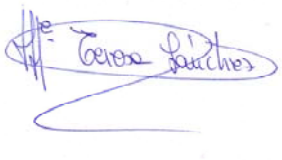
para aspirar al grado de Doctor por la Universidad de Córdoba

presentada por la Ingeniero Agrónomo Dña. *Ana Belén Cabezas Serrano*

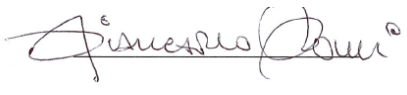
La Doctoranda

Fdo.: Ana Belén Cabezas Serrano

VºBº Los Directores



Fdo.: Profª. Mª Teresa Sánchez Pineda de las Infantas



Fdo.: Prof. Giancarlo Colelli

2013

UNIVERSIDAD
D
CORDOBA

Departamento de Bromatología
y Tecnología de los Alimentos

Mª TERESA SÁNCHEZ PINEDA DE LAS INFANTAS, Catedrática de Universidad del Departamento de Bromatología y Tecnología de los Alimentos de la Universidad de Córdoba (España) y GIANCARLO COLELLI, Catedrático de Universidad del Department of Science Agriculture, Food, & Environment (SAFE) de la Universidad de Foggia (Italia)

I N F O R M A N:

Que la Tesis titulada "**ESTRATEGIAS DIRIGIDAS A RETRASAR EL PARDEAMIENTO ENZIMÁTICO EN PRODUCTOS DESTINADOS A LA IV GAMA: ALCACHOFAS Y PATATAS**", de la que es autora Dña. Ana Belén Cabezas Serrano, ha sido realizada bajo nuestra dirección durante los años 2006-2013; y cumple las condiciones académicas exigidas por la Legislación vigente para optar al título de Doctor por la Universidad de Córdoba.

Y para que conste a los efectos oportunos firman el presente informe en Córdoba a 13 de febrero de 2013.

Fdo.: Profª. Mª Teresa Sánchez Pineda de las Infantas

Fdo.: Prof. Giancarlo Colelli

TÍTULO DE LA TESIS:

ESTRATEGIAS DIRIGIDAS A RETRASAR EL PARDEAMIENTO ENZIMÁTICO EN PRODUCTOS DESTINADOS A LA IV GAMA: ALCACHOFAS Y PATATAS

DOCTORANDA:

ANA BELÉN CABEZAS SERRANO

INFORME RAZONADO DE LAS DIRECTORAS DE LA TESIS

(se hará mención a la evolución y desarrollo de la tesis, así como a trabajos y publicaciones derivados de la misma).

La Tesis, cuyo título se menciona arriba ha podido adaptarse, desde sus inicios, a la metodología y el diseño programados, derivando todo ello en la obtención de resultados de indudable relevancia científica y tecnológica.

En primer lugar, hay que destacar que el trabajo de investigación desarrollado en esta Tesis ha permitido establecer las bases científico-técnicas para la selección de variedades de patata y alcachofa destinadas a su procesado como productos de IV Gama. Se ha determinado entre las variedades comerciales de dichas hortalizas, disponibles en el mercado, aquéllas que resultan más idóneas para su elaboración como producto mínimamente procesado.

Asimismo, se ha analizado el efecto de diversos agentes anti-antioxidantes así como de distintas dosis a aplicar, en la vida comercial de alcachofas y patatas mínimamente procesadas, al objeto de determinar cuál es el mejor agente y la dosis óptima a utilizar para mantener la calidad poscosecha de dicho producto, incrementando al mismo tiempo, su vida comercial.

Por último, se han optimizado las condiciones físico-químicas del tratamiento antioxidante y valorado el efecto que éste tiene sobre el pardeamiento y atributos cualitativos de alcachofas mínimamente.

Lo anteriormente expuesto justifica plenamente que la forma más idónea de presentación de esta Tesis Doctoral sea el compendio de publicaciones científicas.

La doctoranda en el transcurso de su tesis doctoral ha tenido la posibilidad de formarse en Tecnología Poscosecha de Productos Vegetales Frescos y Mínimamente Procesado. La tesis ha sido dirigida en el régimen de cotutela académica por los Profesores Sánchez Pineda de las Infantas de la Universidad de Córdoba y Giancarlo Colelli, de la Università degli Studi di Foggia (Italia). Asimismo, la doctoranda ha complementado su formación realizando una estancia de 28 meses en el Department of Science of Agriculture, Food,

& Environment (SAFE) de la Università degli Studi di Foggia (Italia) bajo la supervisión del Prof. Giancarlo Colelli.

Los trabajos publicados en revistas indexadas JCR relacionados con los resultados de la Tesis son los siguientes:

1. Cabezas-Serrano, A.B., Amodio, M.L., Cornacchia, R., Rinaldi, R. Colelli, G. 2009. Suitability of five different potato cultivars (*Solanum tuberosum* L.) to be processed as fresh-cut product. Postharvest Biology and Technology 53 (3), 138-144.

2. Cabezas-Serrano, A.B., Amodio, M.L., Cornacchia, R., Rinaldi, R., Colelli, G. 2009. Screening quality and browning susceptibility of five artichoke cultivars for fresh-cut processing. Journal of the Science of Food and Agriculture 89 (15), 2588-2594.

3. Rinaldi R., Cabezas-Serrano A.B., Cornacchia R., Amodio M.L., Colelli G., 2010. Response of fresh-cut potato cubes of three different varieties to anti-browning treatments. Acta Horticulturae 876, 319-324.

4. Cornacchia, R., Cabezas-Serrano, A.B., Amodio, M.L., Colelli, G. 2011. Suitability of 4 potato cultivars (*Solanum tuberosum* L.) to be processed as fresh-cut product. Early cultivars. American Journal of Potato Research 88 (5), 403-412.

5. Amodio, M.L., Cabezas-Serrano, A.B., Peri, G., Colelli, G. 2011. Post-cutting quality changes of fresh-cut artichokes treated with different anti-browning agents as evaluated by image analysis. Postharvest Biology and Technology 62 (2), 213-220.

6. Cabezas-Serrano, A.B., Amodio, M.L., Colelli, G. 2013. Effect of solution pH of cysteine-based pre-treatments to prevent browning of fresh-cut artichokes. Postharvest Biology and Technology 75, 17-23.

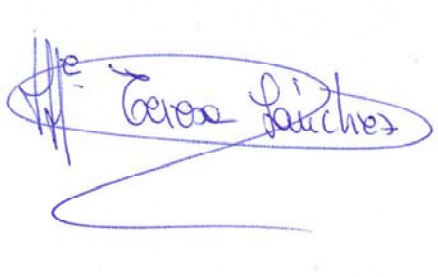
Asimismo, durante el periodo de realización de su tesis doctoral, la doctorando ha publicado igualmente, los siguientes trabajos de investigación:

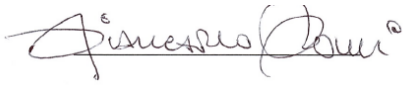
7. Amodio M.L., Cabezas-Serrano A.B., la Zazzera M., Cibelli F., Raimondo M.L., Carlucci A., Colelli G., 2010. Effetto della cisteina sul controllo dell'imbrunimento e della crescita microbica in carciofo (Cynara cardunculus L. subsp. scolymus (L.) Hayek) di IV gamma. Italus Hortus 17 (3), 87-91.

8. Amodio M.L., Cabezas-Serrano A.B., Rinaldi R., Colelli G., 2007. Implementation of rating scales for visual quality evaluation of various vegetable crops. In: Kader A.A., Cantwell M. Produce Quality Rating Scales and Color Charts. Univ of California (Eds.), Davis CA-USA. Postharvest horticulture series no.23. September 2004, revised may 2007.
9. Cabezas-Serrano A.B., Rinaldi R., Amodio M.L., Colelli G. 2007. Effetto dell'atmosfera di conservazione sulla conservabilità di una zuppa pronta a base di ortaggi e legumi. Atti V Conv. AISSA "Relazione Suolo, Pianta, Atmosfera: Sicurezza e Qualità delle Produzioni Agroalimentari e Tutela dell'Ambiente" Foggia. pp. 42-43.

Por todo ello, se autoriza la presentación de la tesis doctoral.

Córdoba, 22 de Febrero de 2013





Fdo.: Mª Teresa Sánchez
Pineda de las Infantas
Universidad de Córdoba (España)

Fdo.: Giancarlo Colelli
Università degli Studi di Foggia (Italia)

A mi abuelo Juan,
espejo en el que mirarme

Agradecimientos

Deseo expresar mi sincera gratitud y reconocimiento a todas las personas que han hecho posible la realización de este Trabajo de Investigación:

Al Prof. Giancarlo Colelli, Catedrático de Universidad del Dipartimento di Scienze Agrarie, degli Alimenti e dell'Ambiente de la Università di Foggia (Italia) y codirector de esta Tesis.

A la Dra. María Teresa Sánchez Pineda de las Infantas, Catedrática de Universidad del Departamento de Bromatología y Tecnología de los Alimentos de la Universidad de Córdoba, y codirectora de esta Tesis.

A la Dra. Maria Luisa Amodio, Profesora Titular de Universidad del Dipartimento di Scienze Agrarie, degli Alimenti e dell'Ambiente de la Università di Foggia (Italia).

A los Departamentos di Scienze Agrarie, degli Alimenti e dell'Ambiente de la Università di Foggia (Italia), de Bromatología y Tecnología de los Alimentos y Producción Animal de la Universidad de Córdoba (España).

A mi familia, por su apoyo incondicional durante todo el tiempo que ha durado la realización de esta Tesis Doctoral.

Por último, a todos aquellos que durante estos años se han interesado por el desarrollo de esta Tesis, muchas gracias.

Índice

ÍNDICE DE TABLAS

ÍNDICE DE FIGURAS

Resumen

RESUMEN

La IV Gama de productos hortofrutícolas ofrece alimentos naturales, frescos, de alto valor nutricional y fáciles de preparar. Todas estas características han favorecido el crecimiento que en los últimos años ha experimentado el sector, al haberse adaptado a las necesidades de la sociedad actual, caracterizada por un ritmo de vida que impone recurrir a comidas rápidas y fáciles de elaborar, sin renunciar a una alimentación sana. Esta situación ha motivado que se hayan dedicado esfuerzos y recursos al desarrollo de nuevos productos lavados, cortados y preparados en fresco, listos para su consumo en crudo o cocinado.

En la actualidad existen gran variedad de hortalizas frescas cortadas siendo las ensaladas las más consumidas. Sin embargo, el mercado carece de algunos productos como es el caso de la alcachofa y de la patata, que teniendo importantes cualidades nutritivas y culinarias y, un papel importante dentro de la dieta mediterránea, requieren tediosas operaciones para su preparación; siendo además productos con importantes problemas de pérdida de calidad debido a su sensibilidad al pardeamiento.

El objetivo principal de esta Tesis Doctoral ha sido el desarrollo y evaluación de estrategias destinadas a retrasar el pardeamiento enzimático de alcachofa y patata. Todos los ensayos han sido realizados utilizando la misma forma de presentación. Así, la alcachofa presentada en cuartos mientras que la patata se analizó en cubos de 1 cm^3.

Las estrategias abordadas se centraron inicialmente en la búsqueda de variedades de alcachofa y patata idóneas para el procesado IV Gama, evaluando tanto su respuesta al pardeamiento a través de parámetros de apariencia visual (medida de parámetros de color y valoración mediante escalas), como su calidad nutricional a través de parámetros de calidad interna (medidas de actividad enzimática, contenido en fenoles, contenido en vitamina C y actividad antioxidante).

Una vez seleccionadas las variedades de patata y alcachofa más idóneas para el procesado como IV Gama, se estudiaron y evaluaron distintos agentes antioxidantes,

inhibidores de la acción del pardeamiento durante la conservación del producto, analizando para ello parámetros de apariencia visual.

Posteriormente, se llevó a cabo la optimización del tratamiento antioxidante con cisteína en alcachofa cortada, evaluando el efecto del mismo sobre el pardeamiento enzimático mediante el análisis de parámetros de calidad interna y el aspecto exterior del producto estudiado.

Los resultados obtenidos permiten afirmar que tanto en alcachofa como en patata las diferencias detectadas en la composición química de las variedades influyeron notablemente en su idoneidad para ser procesadas como producto IV Gama.

Asimismo, es posible afirmar que los tratamientos antioxidantes utilizados dieron lugar a diferentes grados de supresión del pardeamiento, afectando la calidad nutricional de alcachofas y patatas. Además, y como ya se ha indicado anteriormente, la respuesta a un mismo tratamiento puede variar dependiendo de la variedad utilizada.

Por otra parte, en los resultados obtenidos se pone de manifiesto la influencia que la variación del pH puede tener en la eficacia del tratamiento de cisteína sobre la inhibición del pardeamiento enzimático de alcachofa IV Gama, evaluado tanto por el aspecto exterior como por parámetros de calidad interna de dicho producto mínimamente procesado.

Finalmente destacar que los resultados obtenidos de este Trabajo de Investigación suponen un paso adelante en la investigación y desarrollo del proceso de elaboración de alcachofa y patata como productos de IV Gama, lo que facilitaría la presencia de productos con alto valor añadido y alta calidad nutricional en el mercado de las hortalizas mínimamente procesadas.

Abstract

ABSTRACT

Fresh-cut products can be considered as natural and fresh foods with high nutritional value and easy to prepare. These characteristics have contributed to the growth of the fresh-cut market in the last decades, since minimally processed foods are successfully adapted to the requirements of the current society in terms of quality and safety. This situation has led to increasing efforts and resources devoted to the development of new fresh-cut products.

Nowadays, there are many kinds of vegetables in the fresh-cut products market although salads, in various types and forms, are the most consumed. However, so far the fresh-cut produce market lacks products like artichokes or potato, which, with their high nutritional values and culinary attributes, play an important role in the standards of the Mediterranean diet. In addition these products require tedious operations for their preparation which make them the more convenient as a ready-to-use product; on the other hand they have substantial quality loss problems due to their high susceptibility to browning after cutting.

The main objective of this PhD Thesis was the development and evaluation of strategies to delay browning in fresh-cut artichoke and potato. Trials were performed always using the same product shape: artichokes were cut in quarters whereas potatoes where cut in cubes of about 1 cm^3.

Initially, strategies were focused on the screening of cultivars suitable for fresh-cut processing. The response to post-cutting browning was evaluated in term of visual appearance (colour measurement and appearance evaluation), enzyme activity, and nutritional quality (phenolic content, vitamin C content and antioxidant activity).

After screening the most suitable cultivars for minimally processing, assays were performed in order to assess the capacity of different antioxidant agents available for the inhibition of browning during shelf-life in fresh-cut artichoke and potato. The goal in these tests was to evaluate the response of plant material to different antioxidant treatments focusing on relative changes of the attributes of colour and appearance.

Subsequently, trials were conducted in order to optimize the treatment with cysteine on fresh-cut artichokes, previously selected among other antioxidants, evaluating its effect on enzymatic browning, as measured by attributes of colour and appearance.

Results obtained confirm that differences among tested artichoke and potato cultivars, influenced their suitability for processing as fresh-cut product.

It is also possible to state that the antioxidant treatments produced different degrees of suppression of browning, also showing an effect on the final nutritional quality of artichoke and potato. Furthermore, the response to the same treatment varied depending on the cultivar analysed.

Finally, the results obtained pointed out the effect of the solution pH of cysteine-based treatments to prevent browning of fresh cut artichokes, as measured by attributes of visual appearance and quality.

Therefore, the results of this research can be considered as a step forward in the research and development of the industrial process of artichoke and potato as fresh-cut products, in order to facilitate the presence of products with high convenience and nutritional value in this market sector.

Capítulo 1

Capítulo 1. INTRODUCCIÓN

Los productos hortofrutícolas constituyen una parte importante de la alimentación humana; pudiéndose consumir como productos frescos o transformados. Representan la principal fuente de vitaminas, fibra y sales minerales, además de poseer micronutrientes beneficiosos para nuestro organismo.

La facilidad de preparación y la apariencia de frescor, que caracterizan a los productos de IV Gama, han proporcionado a industriales y distribuidores una alternativa a las presentaciones comerciales tradicionales, brindando la posibilidad de reducir el progresivo descenso del consumo de hortalizas frescas que venía observándose en los últimos 10 años (1% anual) (MAGRAMA, 2011). Durante el año 2011, se comercializaron en España 53.844 toneladas, de las que 31.229 toneladas correspondían a ensaladas, 22.453 toneladas a verduras y 5.384 toneladas a frutas. Teniendo en cuenta que la producción nacional total de frutas y verduras se estima en unos 30 millones de toneladas al año, la IV gama supone, actualmente, sólo un 0,2% de la producción, si bien experimenta un crecimiento anual continuo (Monje, 2012).

Los productos de la IV Gama tienen una vida comercial más reducida que la del producto fresco del que proceden debido principalmente a las operaciones de corte y preparación, las cuales provocan daños mecánicos a los tejidos, inducen el pardeamiento enzimático, provocan la pérdida acelerada de la consistencia y una mayor susceptibilidad a los microorganismos (Ahvenainen, 1996).

La fase de acondicionamiento tras el corte se muestra como crítica dentro del proceso de transformación en la IV Gama de productos tales como patata y alcachofa los cuales son muy susceptibles al pardeamiento enzimático. Las enzimas responsables del pardeamiento enzimático (polifenoloxidasas) generalmente, están separadas de sus sustratos (fenoles), por compartimentos celulares. Sin embargo tras la operación de corte, estas barreras se dañan y deterioran entrando en contacto enzimas y sustratos, y dando lugar como producto de las reacciones a compuestos fácilmente polimerizables en pigmentos más grandes y de color oscuro (Toivonen y Brummell, 2008).

En el caso de la patata, diversos estudios publicados incluyen pre-tratamientos tales como el uso del anhídrido sulfuroso y otras sustancias con efecto anti-pardeamiento (Sapers y Miller, 1992; Buta y Moline, 2001; Kaaber, 2002), variando el tratamiento a emplear en función de la variedad de patata estudiada. (Laurila et al., 1998). En alcachofa, Massignan, et al., (2005) aplican recubrimientos comestibles para controlar tal deterioro. Sin embargo, no se ha encontrado en la literatura ninguna evidencia de selección varietal específica para el mínimo procesado de estos productos o el uso de pre-tratamientos con soluciones antioxidantes que retrasen su pardeamiento enzimático.

En este Trabajo de Investigación se plantea la puesta en valor de dos productos: alcachofa y patata, complejos desde el punto de vista de su conservación como productos de IV Gama, para lo cual se estudiarán y evaluarán tanto las variedades a utilizar como la aplicación de distintos tratamientos destinados a prevenir el pardeamiento enzimático, al objeto potenciar la presencia en el mercado de productos innovadores con alto valor añadido, ya sea en términos de facilidad de uso para el consumidor como en términos saludables.

Así, el principal objetivo de esta Tesis Doctoral ha sido generar nuevos conocimientos desde el mayor rigor científico que, además de divulgarse en revistas de repercusión científica internacional, pudiesen ser aplicados a la realidad concreta y peculiar del sector hortícola, y especialmente en el sector de la patata y alcachofa de la IV Gama.

Parte de los resultados del Trabajo de Investigación desarrollado han sido objeto de publicaciones científicas que se presentan en esta Memoria, directamente en el formato requerido por las diferentes revistas, y constituyen la presente memoria de Tesis Doctoral en la modalidad de compendio de artículos científicos.

Con el fin de facilitar su lectura y comprensión esta Memoria se ha estructurado en los siguientes capítulos:

- En el Capítulo 1, se ha tratado de justificar y clarificar de forma muy breve el Trabajo de Investigación desarrollado en la presente Tesis Doctoral.

- En el Capítulo 2, se exponen y concretan los objetivos a alcanzar.
- En el Capítulo 3, se pone de manifiesto la problemática real que ha servido como justificación y punto de partida del actual estudio. En la primera sección, se presentan los aspectos más relevantes relacionados con el procesado de IV Gama en productos hortofrutícolas. La segunda sección y tercera se han orientado a la revisión del potencial de la alcachofa y de la patata como productos de la IV gama. Por último, y en la cuarta sección, se ha realizado una revisión de los fenómenos de pardeamiento en alcachofa y patata analizando las causas y factores que influyen en el mismo, así como los métodos disponibles para su valoración del pardeamiento.
- En los Capítulos 4, 5, y 6 se presentan las aplicaciones y los resultados obtenidos en forma de artículos de investigación, publicados en revistas científicas de difusión internacional.
- El Capítulo 7, recoge las conclusiones obtenidas en esta Memoria.
- Finalmente, en el Capítulo 8, se indican las referencias bibliográficas utilizadas para la elaboración de este Trabajo de Investigación.

Capítulo 2

Capítulo 2. OBJETIVOS

2.1. OBJETIVO GENERAL

El objetivo general de esta Tesis Doctoral es desarrollo y evalución de estrategias destinadas a retrasar el pardeamiento enzimático de alcachofa y patata destinadas a la IV Gama, productos con una vida útil muy reducida por su alta sensibilidad al pardeamiento enzimático.

2.2. OBJETIVOS ESPECÍFICOS

Los objetivos específicos de este Trabajo de Investigación son los siguientes:

1. Selección de variedades de patata y alcachofa destinadas a la producción de productos de IV Gama. [*El cumplimiento del objetivo ha sido abordado en los siguientes artículos científicos: "Suitability of five different potato cultivars (Solanum tuberosum L.) to be processed as fresh-cut products". Postharvest Biology and Technology 53 (2009) 138–144; "Screening quality and browning susceptibility of five artichoke cultivars for fresh-cut processing". Journal of the Science of Food and Agriculture 89 (2009), 2588–2594; y "Suitability of 4 Potato Cultivars (Solanum tuberosum L.) to be Processed as Fresh-Cut Product. Early Cultivars". American Journal of Potato Research 88 (2011), 403-412*].

2. Selección y evaluación de distintos tratamientos antioxidantes a aplicar en patatas y alcachofas de IV Gama, destinados al mantenimiento de la calidad de dichos productos. [*El cumplimiento de dicho objetivo ha sido llevado a cabo en los artículos científicos: "*R*esponse of fresh-cut potato cubes of three different varieties to anti-browning treatments". Acta Horticulturae 876 (2010), 319-324" y "Post-cutting quality changes of fresh-cut artichokes treated with different anti-browning agents as*

evaluated by image analysis". Postharvest Biology and Technology 62 (2011), 213-220].

3. Optimización del tratamiento antioxidante con cisteina para la elaboración de alcachofa IV Gama. [*El cumplimiento de dicho objetivo ha sido llevado a cabo en el artículo científico: "Effect of solution pH of cysteine-based pre-treatments to prevent browning of fresh-cut artichokes" Postharvest Biology and Technology 75 (2013), 17-23*].

Capítulo 3

Capítulo 3. REVISIÓN BIBLIOGRÁFICA

3.1. LOS PRODUCTOS HORTOFRUTÍCOLAS DE LA IV GAMA

3.1.1. Definición

Los productos hortofrutícolas, constituyen una base importante de la alimentación humana consumiéndose tanto como productos frescos o cocinados. Poseen un papel importante siendo la principal fuente de vitaminas, fibras y sales minerales, además de aportar micronutrientes esenciales beneficiosos para nuestro organismo.

En base a la tecnología utilizada para su conservación, los productos hortofrutícolas se clasifican en 5 categorías o gamas:

I Gama: Producto fresco en estado natural (entero).
II Gama: Producto esterilizado (conservas y enlatados).
III Gama: Producto congelado.
IV Gama: Producto fresco mínimamente procesado.
V Gama: Producto elaborado y cocinado habiendo recibido un tratamiento térmico y que requiere mantener la cadena de frío.

Las frutas y hortalizas de IV Gama son frutas y hortalizas frescas preparadas mediante diferentes operaciones unitarias (selección, lavado, pelado, corte, etc.), y envasadas con películas plásticas en atmósfera modificada, de manera individual o colectiva. Son conservadas, distribuidas y comercializadas bajo cadena de frío y están listas para ser consumidas crudas, sin ningún tipo de operación adicional, durante un periodo de vida útil entre 7 y 10 días (Wiley, 1994). Se trata de productos listos para su uso, que permiten un gran ahorro de tiempo, tanto en los hogares, como en el sector de la restauración.

Las principales características de estos productos son: la frescura, ya que conservan las propiedades de las frutas y hortalizas en fresco; la comodidad, ya que son productos listos para su consumo que no requieren limpieza, ni lavado; y el efecto

saludable, contribuyendo a llevar una dieta sana y equilibrada, debido a las aportaciones positivas de las frutas y hortalizas a la salud. Sin embargo la vida útil de estos alimentos está fuertemente limitada por diferentes factores tales como: el pardeamiento de las superficies de corte, una actividad respiratoria intensa, proliferación de microorganismos, control de temperatura durante la conservación, y una correcta elección del envasado (Limbo y Piergiovanni, 2007).

En cuanto a terminología empleada para hacer referencia a estos productos, ésta es amplia, destacando los términos:

- Productos mínimamente procesados (minimally processed).
- Parcialmente procesados (partially processed).
- Preparados para consumir (ready to eat).
- Preparados para cocinar (ready to cook).
- Pre-cortados (pre-cut).
- Pre-preparados (pre-prepared).
- Frescos cortados (fresh-cut).

Analizando de manera exhaustiva la terminología empleada comúnmente para designar a este tipo de productos “mínimamente procesados” o “de IV Gama” existe una pequeña distinción, ya que el término "producto mínimamente procesado" incluye tres variedades de productos: IV gama, V gama y otros productos como los que contienen líquido de gobierno pero con vida útil muy corta. Sin embargo, a nivel europeo no se establece ninguna distinción entre productos mínimamente procesados y de IV Gama (Segura y Díaz, 2001). Por este motivo, en la presente Tesis no se establecerá distinción alguna entre los términos “mínimamente procesados” y de “IV Gama”.

3.1.2. Producción y mercado de la IV Gama

La aparición y desarrollo de los productos de la IV Gama se realiza en los Estados Unidos a mediados de los años 70 para posteriormente trasladarse a Europa hacia el 1980 (Alemania, Suiza, Francia, Holanda, etc.). España se incorpora a este mercado más tardíamente en el 1989.

La cultura gastronómica que caracteriza nuestro País (muy diferente a la anglosajona) ha influenciado la falta de confianza inicial de los consumidores a los productos de IV Gama. Sólo los cambios en los hábitos de la sociedad, unidos a las garantías higiénico-sanitarias que el control del proceso productivo proporciona y el envasado protegido han facilitado la difusión de la IV Gama en España.

En el mercado español la mayor presencia de estos productos corresponde a las hortalizas, mientras que la fruta está en fase de desarrollo. Las mermas durante el proceso de selección y elaboración pueden oscilar entre el 22% y el 70%, lo que justifica la diferencia de precios con las hortalizas sin procesar, ya que estos productos llegan al consumidor sin ningún tipo de desperdicio.

La evolución de la producción de frutas y hortalizas de IV Gama en España (excluida la patata preparada) entre los años 2004 y 2010 se muestra en la Tabla 1.

Tabla 1. Evolución de la producción de frutas y hortalizas de IV Gama

Año	Producción (t)	Δ producción (%)	Millones €	€/kg
2004	35.232		155	4,4
2005	44.598	21,0	180	4,04
2006	53.465	16,6	200	3,74
2007	60.761	12,0	-----	-----
2008	62.681	3,1	200	3,19
2009	66.699	6,0	200	-----
2010	70.600	5,5	337	-----

Fuente: Elaboración propia a partir de datos de MAGRAMA (2011).

En la Tabla 1 se observa que hasta el 2007, el incremento de los volúmenes comercializados de productos IV Gama en España se cuantificaba en cifras de dos dígitos, sin embargo, con la llegada de la crisis en 2008, dicho crecimiento se ha ralentizado. El mercado de la IV Gama está en continua expansión dada la tendencia creciente del volumen total comercializado a pesar de la difícil situación económica, aunque no lo hace al mismo ritmo su volumen de negocio. En 2009, España comercializó 66.699 t de frutas y hortalizas en IV Gama (+ 6% que en 2008), de las cuales 65.377 t fueron de hortalizas y 1.322 t de frutas, lo que ha supuesto un volumen

de negocio próximo a los 200 millones de euros, una cifra que ha experimentado un crecimiento del 2% con respecto al año anterior, mientras que en 2008 fue del 6%.

La cuota de mercado nacional de la IV Gama respecto al total del sector de frutas y hortalizas es del 1,3% (200 M€ de facturación frente a los 15.028 M€ estimados para el 2009 por el FEPEX para el sector de frutas y hortalizas en general). A nivel de la UE, la cuota es mayor (6-8%) con países como el Reino Unido, Francia o Italia a la cabeza en el consumo (FEPEX, 2009).

La concentración de consumo per cápita (representado en kilos) de frutas y hortalizas por Comunidades Autónomas en el año 2010 se representa en la Figura 1.

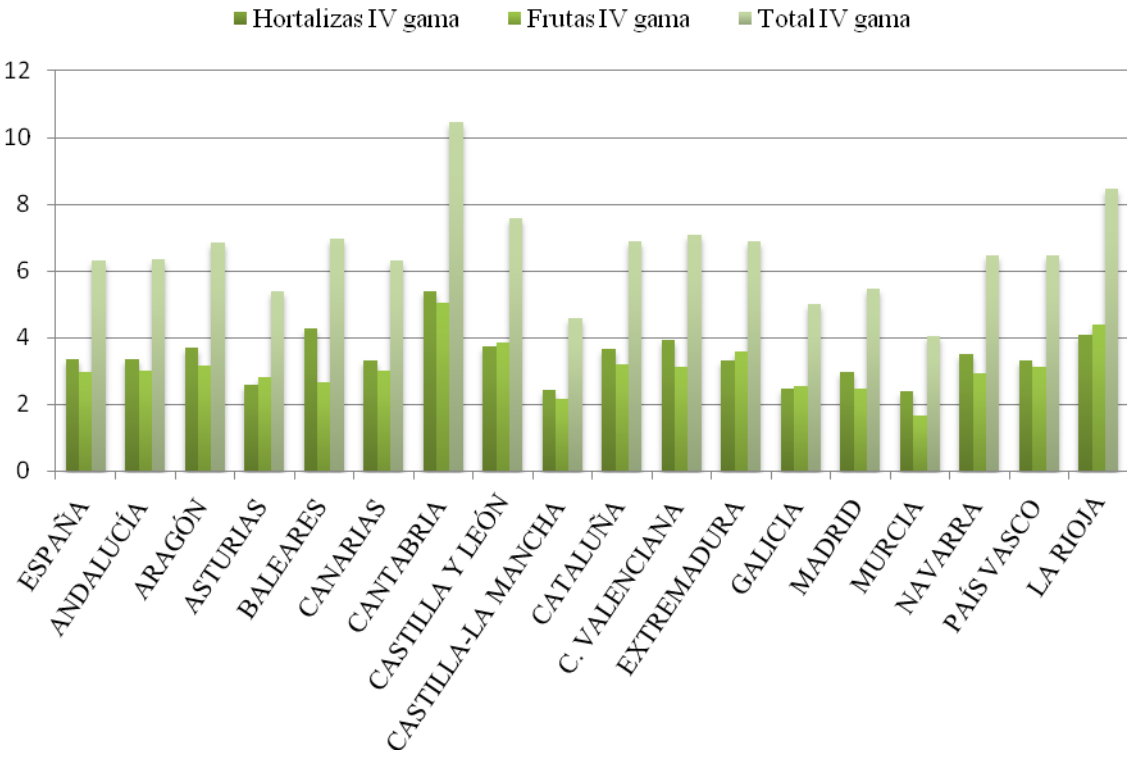


Figura 1. Consumo *per cápita* de frutas y hortalizas IV Gama en 2010

Fuente: Elaboración propia a partir de datos MAGRAMA (2011).

Los datos representados en la Figura 1 muestran que Cantabria cuenta con la mayor demanda de productos IV Gama, muy por encima de la media española, mientras que Murcia es la comunidad autónoma que menos demanda estos productos probablemente por la cercanía de la materia prima.

En la distribución de la industria de la IV Gama cobran gran importancia las grandes marcas de distribución como canal de comercialización preferencial ya que solo la gran distribución puede garantizar la continuidad de conservación de la cadena de frío durante la vida útil de estos productos.

Las especies más empleadas en la IV Gama en España pueden agruparse por: especies de hoja (lechuga, espinaca, escarola, canónigos, baby leaf); las de fruto (berenjena, melón, tomate, pepino, pimiento); las raíces, bulbos e inflorescencias (zanahoria, cebolla y brásicas). En 2011, el 58,2% de la producción (t) correspondió a ensaladas, seguido de verduras 41,7% y el 0,1% frutas (Monje, 2012).

3.1.3. Ingeniería del proceso de elaboración de los productos IV Gama

Los productos IV Gama deben de sufrir una serie de operaciones desde su recolección en el campo hasta llegar a manos del consumidor. Estas operaciones son las siguientes:

- Recolección de la materia prima.
- Recepción.
- Acondicionamiento/Inspección.
- Corte.
- Lavado.
- Secado.
- Pesado.
- Envasado.
- Distribución.

Los productos vegetales son recolectados una vez que alcanza su estado óptimo de madurez o bien se recolectan con el grado de madurez que exija el fabricante. Una vez recolectadas las frutas y hortalizas se preenfrían para que no pierdan su calidad. La fase de limpieza se realiza con agua clorada para disminuir el ataque microbiano. Posteriormente se cortan con una maquinaria especializada, y se envasan en recipientes ya sean bolsas de plástico o bandejas en atmósfera modificada que consiste en una

mezcla de gases que tiene como objeto disminuir la concentración de oxígeno del aire y aumentar la concentración de otro gas. Por último, el envase se mantiene a una temperatura de refrigeración para evitar la proliferación de microorganismos.

Las plantas de manipulación y procesado del producto se caracterizan por:

- El acondicionamiento frigorífico de sus salas (8ºC) y sus cámaras de almacenamiento (entre 0 y 5ºC).
- Un riguroso sistema de control de riesgos higiénicos, normalmente conocidos, como Análisis de Peligros y Puntos de Control Críticos (APPCC).
- Automatización casi total de las instalaciones y maquinaria productiva.

El diagrama de flujo del proceso general de elaboración de frutas y hortalizas mínimamente procesadas se indica en la Figura 2.

Recolección de las materias primas.

La materia prima se recolecta cuando se alcanzan las condiciones óptimas de su madurez. La recolección y selección de la materia prima es un paso muy importante para obtener un producto atractivo y de alta calidad para su distribución en el mercado. Se requieren variedades más específicas para la obtención de productos de alta calidad con unos controles y condiciones de cultivo determinadas. La correcta selección de la variedad es de importancia crucial ya que puede simplificar las etapas y tratamientos que han de ser aplicados (Weller et al., 1997; Gorny et al., 2000).

Durante la recolección se debe:

- Constatar que se hayan respetado estrictamente los tiempos de carencia de los fitosanitarios utilizados, sobre todo en el caso de aquellos tratamientos aplicados cercanos a la cosecha.
- Mantener el orden en el lugar de cosecha, pues colabora con la higiene, eficiencia y rapidez en el desarrollo de las tareas.

Figura 2. Diagrama de flujo del proceso de elaboración de frutas y hortalizas frescas mínimamente procesadas

Fuente: Sanchez, 2004.

- Cosechar en el estado de madurez apropiado para cada producto, con el método de separación acorde a la especie de que se trate (tirar, cortar, retorcer, descalzar, etc.).

- Tomar una muestra del producto, con el grado de madurez, tamaño y color, aceptables para ser cosechados y dejarla como referencia a los jefes de cuadrilla. Dar indicaciones claras antes de comenzar el trabajo, y comprobar que el personal ha comprendido las mismas.

- Evitar realizar la tarea en horas de temperaturas elevadas, cuando todavía hay rocío, tras una lluvia o con alta humedad ambiental.

- Recoger del suelo sólo aquellos productos que se desarrollan directamente sobre el mismo o subterráneamente, por ejemplo: cebolla, ajo, batata, zanahoria, etc. Bajo ningún concepto, se dejarán tirados en el campo restos de cosecha o las frutas/hortalizas que se caen o permanecen en el suelo o planta por cualquier causa, pues éstas se pudrirán y contaminarán el lugar manteniendo elevado el nivel de desarrollo microbiano. Se recogerán y eliminarán en la forma apropiada (quemado, enterrado, etc.).

- Se deberán tratar de recolectar los productos con la menor cantidad de tierra y barro.

- En el caso que se apilen, no se llenarán totalmente los recipientes, a fin de no deteriorar el producto.

- Durante el llenado de los recipientes en el campo, es aconsejable mantenerlos cubiertos o a la sombra, para evitar la acción del sol.

- Se trasladará rápidamente el producto desde el campo al establecimiento de procesado y envasado.

Recepción.

Desde el punto de vista industrial el proceso comienza con la recepción de frutas y hortalizas. La materia prima llega en camiones introducida en cajas, las cuales a su vez se organizan en palets. Cada vez que se reciba una nueva partida de vegetales se

efectuará una toma de muestras representativa para garantizar su buen estado sanitario y evaluar su calidad al mismo tiempo.

Pre-enfriamiento.

La pre-refrigeración de frutas y hortalizas consiste en la extracción del calor que contienen tan rápidamente como sea posible después de la recolección, y reducir su temperatura a niveles adecuados. Esta técnica constituye el primer factor aplicable para ralentizar los procesos biológicos y permite reducir el progreso de la senescencia y el desarrollo de daños y alteraciones.

El término pre-refrigeración es empleado en la manipulación de productos hortofrutícolas para reflejar la eliminación del calor durante su preparación para la expedición al mercado o conservación frigorífica, que se debe realizar en un tiempo inferior a 24 horas. Se realiza mediante aire forzado o hidro precooling para rebajar la temperatura a 7ºC en un tiempo corto de 8 minutos a un máximo de 2 horas (Rosen y Kader, 1989). Para obtener estos beneficios la pre-refrigeración debe ser eficaz, es decir, absorber el calor en un tiempo mínimo.

Acondicionamiento.

El acondicionamiento es una fase de preparación de la materia prima que consiste en la separación de las partes no comestibles. Puede suponer una pérdida del 20-70 % del producto, por tanto es una fase determinante en el coste y calidad del producto final. El porcentaje de desechos también varía según las condiciones en que llegue el producto, influyendo factores intrínsecos al material vegetal como la variedad o capacidad de autoblanqueo; y otros ajenos al mismo: meteorología, recolección y transporte entre otros (Sánchez, 2003).

Selección y limpieza.

El proceso de manipulación del producto debe realizarse de una forma cuidadosa evitando así posibles daños una vez realizada la recolección, otro de los puntos a tener en cuenta es el transporte, que debe efectuarse de forma rápida para evitar posibles

contaminaciones. Para el proceso de limpieza se requiere un perfecto estado higiénico de los utensilios. Asimismo el estado de conservación de las maquinarias de limpieza debe ser el adecuado.

El lavado y desinfección de los productos de IV Gama se realiza con agua fría a una temperatura de 3 a 4ºC. Se recomienda utilizar unos 8 a 10 litros de agua por cada kilogramo de producto procesado. El agua utilizada debe ser controlada periódicamente para saber si su uso es apto o no. Periódicamente se revisa en las plantas, las instalaciones de agua por evitar posibles deterioros de éstas. Para la desinfección se utiliza hipoclorito de sodio en una concentración de 100 a 150 ppm (Sánchez, 2004).

Los hipocloritos se utilizan fácilmente sin necesidad de equipo especial si bien, la dosificación es exacta. La actividad germicida de los hipocloritos disminuye con la concentración, especialmente en agua alcalina (pH > 8,5), de ahí que se deba regular el nivel de pH del agua. Cuando el gas cloro y los hipocloritos se añaden al agua se produce fácilmente ácido hipocloroso que es el que se considera como el agente germicida. La actividad germicida es directamente proporcional a la concentración del HOCl no ionizado de la solución (Jay, 1992).

Por otro lado, otros sistemas como el ozono se están utilizando actualmente en la industria en concentraciones muy bajas (0,2-1 ppm) durante tiempos de exposición prolongados, con el fin de inhibir el crecimiento fúngico durante la conservación a bajas temperaturas.

Durante el proceso de secado de productos IV Gama, se elimina el exceso de humedad producido por el lavado para así evitar la aparición de microorganismos que suelen aparecer cuando el proceso de secado no se realiza de forma de correcta. Si se somete el producto a un secado con excesiva rapidez también se podría dañar el material a secar, por lo que debe realizarse de forma controlada.

Pelado, cortado y rallado.

Las operaciones de corte y pelado inducen en los productos la aceleración de la respiración, provocando daños mecánicos y ablandamiento del tejido vegetal. Los

tejidos cortados constituyen barreras menos eficaces a la difusión de los gases y toleran concentraciones más elevadas de O_2 y niveles inferiores de CO_2 que los productos intactos. De esta manera se llega a duplicar y hasta cuadruplicar su intensidad respiratoria como respuesta al "stress" de corte (Sánchez, 2003). El motivo de efectuar el cortado después del prelavado es el de evitar la contaminación de la superficie de corte con los microorganismos procedentes de la superficie exterior (Sánchez, 2004).

Es importante mantener la temperatura de las frutas y hortalizas por debajo de los 4ºC para detener ese aumento de actividad. De esta forma, la temperatura de la sala de procesado se fijará en 0ºC al objeto de limitar el posible aumento de la temperatura del producto a lo largo del proceso de elaboración (Sánchez, 2003).

Limpieza, lavado y secado.

Frutas y hortalizas cubiertas de tierra, barro o arena deberán limpiarse cuidadosamente antes de su procesado. El segundo lavado se deberá efectuar después del pelado o cortado. El lavado después del pelado y cortado elimina microorganismos y tejidos fluidos reduciendo el crecimiento microbiológico y la oxidación enzimática.

Conservantes tales como cloro, ácido cítrico u ozono deberán usarse en las aguas de lavado para la reducción del número de microorganismos y retrasar la actividad enzimática al mismo tiempo que para incrementar el tiempo de conservación. Una cantidad de 100-200 mg/litro de cloro o ácido cítrico es efectiva en el agua de lavado antes o después del pelado y/o cortado para incrementar el tiempo de conservación. Cuando se utilicen derivados del cloro, el producto deberá ser aclarado (Wiley, 1994).

Secado superficial.

El secado superficial consiste en la eliminación de los fluidos celulares que recubren el producto después del corte, aspecto este fundamental para la conservación del producto, y que se efectúa mediante la eliminación del exceso de agua en el tejido. Por tanto, el almacenamiento del producto "seco" es un factor importante en la extensión de la vida útil de los productos mínimamente procesados.

Mezclado.

Los alimentos combinados tales como ensaladas requieren un mezclado y preparación antes del envasado. El objetivo del mezclado en el procesado de frutas y hortalizas es asegurar que la mezcla homogénea se forma y mantiene con un bajo gasto energético.

Pesado y envasado.

El pesado y envasado de los productos troceados es la fase final del proceso. El material llega hasta la pesadora que normalmente se encuentra íntimamente ligada a la envasadora. Los tipos de envases plásticos más utilizados para los productos de la IV Gama son las bolsas, aunque el empleo de barquetas impermeables (selladas con plásticos de alta permeabilidad o introducidas en bolsas) son también muy empleadas por su mayor resistencia mecánica.

Existen tres categorías de envasado de productos mínimamente procesados siendo éstas:

- Envasado unitario.
- Envasado de transporte.
- Envasado de unidades de carga.

Envasado unitario: Es un envasado que va destinado al consumidor final. El tipo de envases utilizados son bolsas de plástico cerradas, bandejas recubiertas con una película de plástico, bandejas de plástico rígidas también llamadas tarrinas, cerradas también en su parte superior con una película de polímero. En definitiva, son muchos los tipos de envases que se utilizan en este tipo de envasado. Las envolturas que cubren la parte superior del envase suelen ser de polietileno o policloruro de vinilo. Son películas extensibles o adheridas a las bandejas y en algunas ocasiones suelen ir perforadas o no.

Envasado de transporte: Este tipo de envasado se utiliza para facilitar la manipulación manual y para envasar cantidades fijas de producto. El envasado de

transporte de productos utiliza contenedores del tipo como cajas de cartón, de madera o de pasta rígida.

Envasado de unidades de carga: Este tipo de envasado es el que utiliza el palet con el fin de reducir los costes de manipulación. El trabajo de carga y descarga está facilitado por la utilización de unos equipos mecánicos y móviles que permiten el traslado de los palets de un lugar a otro del almacén reduciendo daños y aplastamientos. Estos equipos mecánicos son las carretillas elevadoras y las de horquilla.

En cuanto al método de envasado, son aconsejables el uso de atmósferas modificadas las cuales se caracterizan por proporcionar una determinada concentración de O_2 y CO_2 en el envase para así ir reduciendo de forma progresiva la velocidad de respiración de los productos sin llegar a inducir la anaerobiosis, debido a que ésta favorecerá la fermentación del producto, generando olores y sabores desagradables, y/o favoreciendo el desarrollo de bacterias anaérobicas como *Clostridium botulinum* (*Yahia,* 1995).

El envasado de frutas y hortalizas en atmósfera modificada es un proceso en el que el envase cerrado interactúa con el producto de tal forma que se alcanza un equilibrio en la atmósfera interna que se reduce la velocidad de respiración, la pérdida de humedad por transpiración e incrementa la fase de latencia del desarrollo microbiano.

Etiquetado.

Nitratos en las ensaladas: Se debe analizar la cantidad de nitratos presentes en las ensaladas, ya que los vegetales acumulan altos contenidos en nitratos, como es el caso de la lechuga, espinaca y acelga. Estos nitratos se acumulan durante el cultivo en los vegetales debido al empleo de abonos nitrogenados. Los nitratos pueden transformarse y pasar a nitritos siendo perjudiciales para el ser humano.

Estado sanitario: Las ensaladas de IV Gama deben ser manipuladas con cuidado debido a que presentan cierta cantidad de agua y no reciben un tratamiento térmico para desactivar la acción de los microorganismos causantes de toxicidad alimenticia. Por

ello, debe de manipularse correctamente empleando todas las medidas higiénicas disponibles y manteniendo una cadena de frío constante para el producto.

Plaguicidas: El uso de plaguicidas para controlar las plagas (hongos, insectos, malas hierbas, etc.) hace que aparezcan en algunos casos en las ensaladas, pero en baja medida de toxicidad, es decir, ninguno supera las cantidades tóxicas admitidas por la Ley.

Almacenamiento a bajas temperaturas.

La refrigeración es una tecnología ya que permite alcanzar una temperatura óptima para prolongar el tiempo de vida de un producto determinado.

Durante el almacenamiento a bajas temperaturas de los productos IV Gama, se reduce la temperatura con el fin de disminuir la actividad enzimática y el crecimiento microbiano. Normalmente se requiere una temperatura de refrigeración de 1ºC a 4ºC.

Distribución y venta.

El transporte de los productos IV Gama tiene un importante papel, ya que, permite de forma rápida la distribución de éstos por toda la geografía española y resto de países extranjeros como Reino Unido, Francia (mayores importadores).

En el caso que las frutas y hortalizas mínimamente procesadas sean envasadas con algún material que actúe como barrera a los gases y vapor de agua, no será necesario cuidar la humedad, ni el contenido de gas etileno en el recinto durante el transporte, lo que sí se deberá controlar en todos los casos la temperatura. Durante el transporte deben respetarse las mismas temperaturas que durante el almacenamiento.

Para controlar la elevación de la temperatura se deberán realizar controles regulares de los equipos de refrigeración y termostatos. Es conveniente el uso de termógrafos para registrar las variaciones de temperatura experimentadas por la carga durante el período de traslado.

3.2. LA ALCACHOFA COMO PRODUCTO DE LA IV GAMA

3.2.1. Generalidades

La alcachofa pertenece a la familia *Asteraceace* (Compuestas), género *Cynara* y especie *Cynara scolimus* L. Es una planta perenne, perteneciente a la familia de las Compuestas. La planta comercialmente dura de 4 a 5 años, pero la tendencia es renovarla cada uno o dos años.

El sistema radicular consiste en raíces suculentas y fibrosas. La raíz puede alcanzar profundidades superiores a los 50 centímetros, extendiéndose a lo ancho de forma similar a la parte aérea, formando conos de hasta 70-90 cm de diámetro en su parte alta. Superficialmente llega a formar un rizoma a partir del que brotan yemas auxiliares de hojas antiguas que pueden producir esquejes. Parte de dicho rizoma puede usarse en multiplicación vegetativa en lo que se conoce como zuecas o palos.

La corona, punto de unión entre tallo y raíz en una planta de roseta como la alcachofa, presenta una serie de yemas en los nudos, éstos originan los hijuelos. La planta posee un tallo en cuyo extremo principal se desarrolla una inflorescencia que se denomina cabezuela. De las yemas axilares del tallo principal se desarrollan ramificaciones que sustentan alcachofas secundarias y terciarias de menor tamaño. La altura de la planta alcanza hasta 1,8 metros. Las hojas son oblongas, aserradas, con los bordes provistos de grandes dientes, de más de un metro de longitud con un nervio central grueso, y con nerviaciones marcadas. A diferencia de las hojas jóvenes, las hojas adultas son muy lobuladas apreciándose en todas ellas, abundancia de pubescencia en el envés. Las flores corresponden a una inflorescencia o alcachofa que es la parte comestible, consta de un receptáculo que se conoce comúnmente como "fondo de alcachofa" y de brácteas que protegen a las flores, cuya base también es comestible.

Las yemas comestibles de la planta de alcachofa están compuestas por un cono de brácteas que se recoge en estado inmaduro, seleccionándose por tamaño y cuando su aspecto es compacto y muestran su coloración verde típica.

Los tallos son acanalados, gruesos, ramificados y con surcos longitudinales; finalizando en inflorescencias, que son el objeto del cultivo de la alcachofa.

Las flores están insertadas en un tálamo terminal carnoso, cubierto por brácteas imbricadas entre sí. En muchas variedades dichas brácteas son espinosas.

El fruto en aquenio, de forma oblonga, es de colores más o menos grisáceos, con manchas pardas o negruzcas.

Sus semillas de color grisáceo, con rayas más oscuras; tienen gran poder de difusión, gracias al cual son trasladadas a grandes distancias por el viento; esto tiene el inconveniente de que luego dan lugar a plantas silvestres que no se parecen en nada a las de origen, ya que son plantas degeneradas y de peor calidad.

La facultad germinativa dura de seis a doce años, tardando en germinar unos veintidós días. El número de semillas contenidas en un gramo es de 27, aproximadamente.

Las alcachofas, como todas las hortalizas y frutos, son organismos vivos incluso serparados de la planta, por tanto prosiguen, incluso de manera más acentuada, los típicos procesos metabólicos de los tejidos vegetales. La vida de los productos hortofrutícolas puede dividirse en tres estados fisiológicos: crecimiento, maduración y senescencia. Durante estos tres estadíos suceden una serie de cambios en su composición que pueden influenciar tanto los aspectos organoléptico y nutricional, como el aspecto exterior. Entre los procesos metabólicos que están íntimamente unidos a la disminución de la calidad y la senescencia de los productos, tienen una gran importancia la respiración, la producción de etileno y todos los procesos de degradación de compuestos como azúcares, ácidos inorgánicos, componentes de las paredes celulares y pigmentos. Además, fenómenos como la pérdida de agua mediante la transpiración, la cual no puede compensarse por el aporte hídrico a través de las raíces de la planta, contribuyen sea de manera directa o indirecta a los fenómenos de deterioro. A la problemática descrita con anterioridad se añade la mayor susceptibilidad a ataques por parte de microorganismos patógenos (principalmente hongos y bacterias), que

determinan la presencia de podredumbres y mohos, dejando estos productos de ser comestibles.

Por tanto, en el periodo de tiempo que va desde la cosecha al consumo final del producto, es muy importante poner a disposición todos los medios que en cualquier modo tiendan a ralentizar los procesos metabólicos. Generalmente, tales medios consisten en controlar los factores ambientales, particularmente la temperatura, la humedad relativa y la composición de la atmósfera de conservación.

Para mantener la calidad durante la vida útil poscosecha, las cabezas de alcachofa deben ser pre-enfriadas a una temperatura inferior a 5ºC, en un tiempo inferior a 24 horas tras la recolección. El enfriamiento por agua (hidrocooling), por aire forzado (air pressure cooling), por vacío (vacuum cooling) y por hielo (ice cooling) son los métodos más comunes de enfriamiento poscosecha en alcachofas, los cuales retrasarán el deterioro, la pérdida de peso y el marchitamiento. Un enfriamiento rápido después de la cosecha, permite alcanzar una temperatura de 2-4ºC, lo cual es necesario especialmente en otoño y primavera (Colelli y Calabrese, 2009). Las técnicas de pre-enfriamiento por aire forzado y el vacío son las más utilizadas.

Las alcachofas poseen una intensidad respiratoria y una tasa de transpiración elevada debido al parámetro superficie/volumen; por este motivo, se considera un producto altamente perecedero. Como puede observarse en la Tabla 2 a 20ºC, el anhídrido carbónico emitido es de 184 mg/kg/h (469 kcal/t/h).

Tabla 2. Actividad respitaria y producción de calor de la alcachofa

Parámetros	Temperatura (°C)				
	5	10	15	20	25
Respiración (mg CO_2 /kg/h)	43	70	110	184	223
Producción de calor (Kcal/t/h)	110	196	280	469	569

Fuente: Elaboración propia a partir de Bianco (1990).

La alta actividad actividad respiratoria de este producto da lugar a una gran pérdida de peso durante la conservación. Por ello, para mantener la calidad durante la conservación de las alcachofas es importante que justo después de la cosecha o como máximo durante la misma jornada, se sometan a prerefrigeración hasta llevarlas a 3-4ºC.

Suslow y Cantwell (1997) establecen que las condiciones óptimas de conservación de la alcachofa son temperatura de 0ºC y humedad relativa superior al 95%. La conservación de las alcachofas en estas condiciones no supera los 21 días ya que que su calidad sensorial y visual se deterioran muy rápidamente. Otros autores indican sin embargo tiempos de conservación más cortos, que no exceden las 2 semanas a 1-2ºC, 10 días a 5ºC y 5 días a 10ºC con humedad relativa >90% (Ryall y Lipton, 1979; Saltveit, 1991).

El control de la humedad relativa es muy importante para la conservación de las cabezas de alcachofa. Así, valores superiores al 95% aseguran una pérdida de peso mínima, evitando la pérdida de turgencia de las brácteas externas y del tallo, y el marchitamiento de las hojas (Lipton y Stewart, 1963; Suslow y Cantwell, 1997). Un estudio realizado por Leroy et al., (2010) mostró que la pérdida de peso aumentó durante la conservación de alcachofas a 4ºC y 60% HR. Asimismo, Agamia (1984) indicó que las pérdidas de peso de la alcachofa se deben a las altas tasas de respitación y transpiración de este producto.

Los síntomas más evidentes de deterioro de las alcachofas son la aparición del color violeta en las brácteas internas incluso en aquellos cultivares que no presentaban este color en el momento de la cosecha. Estas brácteas además de colorearse tienden a ser más fibrosas. Otro síntoma que aparece como causa de descartes en alcachofas, es la aparición de manchas oscuras de color negro, casi siempre localizadas en el tercio inferior de las brácteas y que confieren mal sabor al producto (Bianco, 1990).

De entre todas las posibles modificaciones indeseables que el procesado de IV Gama ocasiona, es el pardeamiento enzimático (del que se hablará en el apartado 4) el principal responsable de la pérdida de calidad, y es particularmente intenso en el caso de la alcachofa, lo que hace que el desarrollo de elaborados de IV gama de este producto resulte especialmente difícil.

3.2.2. Producción de alcachofa

España es el tercer productor mundial de alcachofa con 166.700 t por debajo de Italia, con 480.112 t y Egipto 215.534 t al año. Les siguen, por orden de importancia, Perú, Argentina, China, Marruecos, Francia, Estados Unidos, y Argelia, con producciones sensiblemente inferiores a los cuatro principales productores (FAOSTAT, 2012).

En general, el 60% de la producción se dirige a la industria y el 40% restante para el consumo en fresco, permaneciendo un 75% en el mercado de interior y siendo el restante 25% exportado el resto del mercado comunitario. La producción de alcachofa para exportación se realiza casi exclusivamente en Murcia, empleándose variedades de tamaño grande y color violáceo, características más demandadas en el mercado exterior (predominantemente en Francia).

Dentro de nuestro País, este cultivo tiene especial importancia en las comunidades autónomas del litoral mediterráneo, especialmente en Murcia, con más de un 40% de la producción nacional en el año 2010. También destaca, la Comunidad Valenciana y Andalucía, las cuales produjeron el 40% de la producción nacional de la campaña 2010 (MAGRAMA, 2011).

3.2.3. Calidad de la materia prima

3.2.3.1. Características físicas de la alcachofa

El capítulo floral de la planta de alcachofa puede presentar formas cilíndricas, cónicas ovoidales, elipsoidales, esféricas o subesféricas. La forma cilíndrica la presentan variedades precoces del tipo “catanese”, la cónica y la ovoidal están presentes en los tipos “espinosos”, la elipsoidal en los tipos “violetas” y, la esférica y la subesférica en los tipos “romanescos”.

El color de las brácteas externas, que representa el color de la alcachofa, varía con las diferentes tonalidades de verde (verde claro, verde oscuro, verde ceniza) y con

los diferentes grados de intensidad de las sombras oscuras y violetas presentes en la superficie de las brácteas hasta convertirse completamente en violeta, repersenta un carácter muy significativo de cada variedad; aunque hay que considerar que la climatología puede alterar las sombras del verde al violeta. Asimismo, el color de las brácteas internas puede ser variar en su tonalidad; algunas variedades presentan brácteas de coloración blanco-verdosa, mientras otras tienen coloración amarillo-verdosa o amarillo pálido con sombras más o menos violetas en relación a la intensidad del color violeta de las brácteas externas. Las brácteas cercanas al cáliz, a menudo, toman coloraciones violetas más evidentes cuando se retrasa la cosecha y bajo altas temperaturas. Esta característica del capítulo de la alcachofa posee gran interés para el producto destinado a la transformación, donde se requieren capítulos con brácteas internas muy claras con ausencia de zonas violáceas.

El estado compacto de la cabeza de la alcachofa está influenciado sensiblemente por la climatología y la forma. Por ejemplo, el tipo cilíndrico presenta frecuentemente las brácteas abiertas cuando la evolución climatológica contempla altas temperaturas y se retrasa la cosecha.

La dimensión de la alcachofa se calcula mediante la medida de la altura (distancia entre el receptáculo y el ápice de la alcachofa) y del diámetro transversal máximo; por tanto, la dimensión está estrechamente correlacionada con el peso de la alcachofa. El calibre máximo transversal determina la valoración comercial del producto.

3.2.3.2. Composición nutricional de la alcachofa

La alcachofa representa un importante componente de la diteta Mediterránea y es una rica fuente de compuestos fenólicos bioactivos y de inulina, fibra y minerales (Lattanzio, 1982; Orlovskaya et al., 2007). Además, poseen un contenido calórico muy bajo, son ricas en minerales (potasio, calcio, fósforo y hierro), siendo su contenido en vitaminas bajo tal y como se describe en la Tabla 3.

Tabla 3. Composición química de alcahofa cultivada (100 g parte comestible)

Parte comestible (g)	34	Potasio (mg)	376
Agua (g)	91,3	Hierro (mg)	1
Proteina (g)	2,7	Calcio (mg)	86
Grasas (g)	0,2	Magnesio (mg)	45
Carbohidratos (g)	2,5	Fósforo(mg)	67
Almidón (g)	0,5	Tiamina (mg)	0,06
Azúcares solubles (g)	1,9	Riboflavina (mg)	0,1
Fibra (g)	5,5	Niacina (mg)	0,5
Energia (Kcal)	22	Vitamina C (mg)	12
Sodio (mg)	133	Vitamina A (µg ret. eq)	18

Fuente: Adaptado de Cannella, 2009.

Las propiedades nutricionales y farmacéuticas de las alcachofas y de sus hojas están unidas a su alto contenido en compuestos polifenólicos e inulina (Lattanzio, 2009). La inulina pertenece al grupo de los polisacáridos de fructosa llamados fructanos, los cuales no se digieren en el intestino delgado porque el hombre carece de los enzimas necesarios para la hidrólisis del fructano. La publicación de datos mostrando la influencia positiva sobre la composición de la microclora intestinal ha motivado el reciente interés en las inulinas. Tambíen hay indicaciones de los efectos beneficiosos en la absorción de minerales, composición lipídica en sangre, y prevención de cáncer de cólom. Además, la inulina es una fibra baja en calorías que tiene potencial para usarlo en la elaboración de alimentos bajos en calorías (Frehner et al., 1984; Pollock, 1986; Darwen y John, 1989; Pontis, 1990; Carpita et al., 1991; Rapaille et al., 1995; Hellwege et al., 1998, 2000; Roberfroid y Delzenne, 1998; Van Loo et al., 1999).

Los compuestos fenólicos componen una de los principales tipos de metabolitos secundarios, con gran variedad de estructuras: entre los compuestos monoméricos y los diméricos, y también otras cuatro clases de fenoles poliméricos: ligninas, taninos, melaninas y suberinas. Hasta ahora, varios miles de estructuras fenólicas se han descrito. Los compuestos fenólicos están presentes particularmente en frutas y hortalizas, donde tienen un papel importante en la determinación del color, apariencia, flavor y sabor (Lattanzio, 2003). La importancia de estos compuestos radica además a su conocida doble acción como protectores contra daños oxidativos causados por los radicales libres (Rice-Evans y Miller, 1996; Llorach et al., 2002; Racchi et al., 2002) y como sustratos de reacciones de pardeamiento oxidativo por mecanismos enzimáticos y

químicos (Lattanzio et al., 1994; Wang et al., 2003). La acción de los fenoles como potentes antioxidantes se debe principalmente a sus propiedades redox, la cual les permite actuar como agentes reductores, donadores de hidrógeno y secuetradores de oxígeno (Rice-Evans y Miller, 1996).

Las sustancias fenólicas más abundantes encontradas en cabezas de alcachofas pertenecen al tipo de los ácidos hidroxicinámicos, tales como coumárico (ácido 4-hidroxicinámico) y derivados del ácido cafeoilquínico (Lattanzio et al., 1994), particularmente el ácido clorogénico (ácido 5-O- cafeoilquínico), ácidos 1,5-di-O-cafeoilquínico y 3,5-di-O-cafeoilquínico (Schütz et al., 2004), y al tipo de los flavonoides, tales como apigenina y luteolina (Lattanzio y Van Sumere, 1987; Shütz et al., 2004), así como diferentes derivados de las cianidinas cafeoilglucósidos (Aubert y Foury, 1981).

Dentro de los derivados del cafeoilquínico, el ácido clorogénico es el componente más abundante (39%), seguido por el ácido 1,5-di-O-cafeoilquínico (21%) y el ácido 3,4-di-O-cafeoilquínico (11%), respecto del total de total ácidos cafeoilquínicos. El contenido de cinarina (ácido 1,3-O-cafeoilquínico) en extractos metanólicos de alcachofa es muy bajo (aproximadamente 1,5%). Entre los flavonoides, los glucósidos de apigenina y luteolina se han detectado en hojas y cabezas de alcachofa, mientras los pigmentos antocianos están presentes sólo en el capítulo floral. Los antocianos son responsables de la mayoría de los tonos azules, violetas, rojos y tintas intermedias de los tejidos vegetales. Desde un punto de vista cuantitativo, esos componentes se consideran constituyentes menores del total del contenido fenólico (cerca del 10% o menos) del tejido de alcachofa (Zhu et al., 2004; Lattanzio et al., 2009).

El contenido fenólico en la parte comestible de la alcachofa en estado de madurez comercial oscila entre 0,5-2% de su peso fresco (3-12% peso seco). Sin embargo, el contenido fenólico (y composición) en las diferentes partes de la planta está influenciadao por el genotipo y factores fisiológicos e ambientales (Di Venere et al., 2005, 2009). Fratianni et al., (2007) demostró que en algunos cultivares, las brácteas internas y el receptáculo mostraban las mayores concentraciones de fenoles, seguidos por las brácteas intermedias y externas y, finalmente, por las hojas. También

demostraron que los polifenoles se acumulan preferentemente in partes específicas de la cabeza de alcachofa y dependiendo del genotipos. Datos publicados por Lombardo et al., (2010), evaluaron la composición en polifenoles de diferentes genotipos confirmando lo anteriormente descrito. Por lo tanto, la conservación de la variabilidad genética encontrada en el germoplasma de alcachofa así como un más amplio cultivo de variedades autóctonas resultaría deseable (Alamanni y Cossu, 2006; Romani et al., 2006). El contenido fenólico disminuye durante el desarrollo del capítulo y el contenido en la madurez comercial se observa en la mitad del contenido durante el desarrollo temprano.

3.2.4. Variedades

Sala y Carpintero (1967) subdividían las variedades españolas en dos grupos: blancas y violetas. Sin embargo, en este último grupo predominan variedades extranjeras (Gil-Ortega, 1999). Por ello se ha opta por clasificar las variedades de alcachofa según su época de recolección en variedades precoces, susceptibles de iniciar la formación de capítulos en otoño, prosiguiéndose en invierno y primavera; variedades tardías, que inician la formación del capítulo al final del invierno; y variedades de media estación, cuya iniciación floral y consecuente la formación de capítulos se produce en un periodo intermedio.

En España la variedad que ocupa prácticamente la totalidad de los campos de alcachofa en un 99% es "Blanca de Tudela". Esta variedad también se cultiva en gran parte de la superficie de Marruecos, Túnez y Argelia. En Chile hay una variedad descendiente de "Blanca de Tudela" cuyo nombre es "Argentina" que ocupa el 70% de las plantaciones de alcachofa del país (Macua et al., 2003).

La principal variedad en Italia es “Violetto di Provenza”, denominada “Violetto foggiano” en Apulia), seguida por la “Catanese” (denominada “Brindisino” o “Molese” en Apulia) (Macua et al., 2003).

En Francia, la variedad principal es “Camus de Bretaña”, de color verde y cuya denominación indica la zona dónde es cultivada. Otra variedad de gran importancia que se cultiva en la zona de los Pirineos franceses es “Macau” (verde), la cual también está

presente en algunas plantaciones en España con el mismo objetivo que "Violetto di Provenza" (Macua et al., 2003).

La variedad "Green Globe" supone el 90% en las plantaciones en Estados Unidos, englobando el área de la bahía de Monterey. En la región costera sur se plantan "Big Heart" y "Desert Globe", mientras que en la región desértica del sureste principalmente se encuentran las variedades "Emerald", "Big Heart" e "Imperial Star".

En Egipto existe una variedad local denominada "Baladi" (color semivioleta), la cual convive con las variedades de semilla "Imperial Star" (verde) y "Green Globe" (semivioleta). Estas dos últimas junto a "A-106", "Lorca" y una variedad violeta llamada "Criolla" que supone el 50% de la superficie nacional se pueden encontrar en Perú (Macua et al., 2003).

Las variedades utilizadas en Argentina son "Francés" (verde con manchas violáceas), "Ñato" (violeta), "Precoz Italiano" (verde oscuro ligeramente violáceo) y "Blanco" de color verde.

"Blanca de Tudela"

Zona de cultivo: Es la variedad dominante en las plantaciones españolas de alcachofa (Gil-Ortega, 2001).

Características morfológicas: La planta es de talla corta (incluyendo el capítulo central). La hoja, de longitud corta, no presenta espinas; el número de lóbulos de presentes en la hoja es bajo y el limbo presenta una intensidad del color verde (del haz). El capítulo es verde claro, compacto, y bien formado, con presencia de antocianos, jaspeado inferior al 5% en la base de las brácteas de la base del capítulo. El receptáculo del capítulo central es de espesor delgado. El capítulo presenta forma cónica-cilíndrica, sección triangular y buena homogeneidad. No presenta espinas (Macua, 1995).

Características productivas: Producción muy temprana, presentando las recolecciones en otoño, invierno y primavera, en el área mediterránea. Planta de vigor medio-bajo.

"Catanese" o "Violetto di Sicilia"

Zona de cultivo: Es la principal variedad cultivada en Italia, predominante en el centro-sur de Italia (Toscana, Apulia, Basilicata y Calabria) y en Sicilia. Esta variedad se cultiva también en Francia, Túnez, Argelia, Egipto e Israel.

Características morfológicas: La planta es de talla pequeña o media, porte intermedio. La hoja tiene color verde, sin espinas, de dimensión media, heterofilia elevada por presencia de hojas con lámina entera más frecuente en los primeros estadíos vegetativos de la planta y en las plantas más precoces, las otras hojas son lobuladas. El capítulo floral es cilíndrico y medianamente compacto, de dimensiones pequeñas o medias, brácteas externas de color verde con presencia de antocionanos y de dimensiones medias, el ápice es redondeado o levemente incisivo, sin espinas aunque en ocasiones puede presentar una pequeña espina violeta; las brácteas internas son de color blanco-verdoso con ligera presencia de antocianos. El pedúnculo es corto o de longitud media y de espesor fino o medio (Dellacecca et al., 1976).

Características productivas: producción muy temprana o temprana, con inicio de la producción en octubre-noviembre en cultivos de regadío. Ciclo productivo largo. La producción de capítulos por planta es media al igual que el peso de los mismos.

"Spinoso Sardo"

Zonas de cultivo: Es la segunda variedad en importancia de Italia, cultivada principalmente en Cerdeña y Liguria.

Características morfológicas: La planta es de talla media y porte erecto. Las hojas son de color verde con espinas y dimensiones medias, poseen una heterofilia elevada por la presencia de numerosas hojas con lámina foliar entera, particualrmente en los primeros estadíos vegetativos de la planta y en aquellas más preconces; las otras hojas son lobuladas. El capítulo principal es cónico y medianamente comopacto, de dimensiones medias, brácteas externas de color verde con bastante presencia del violeta y pardo, son grandes y alargadas, con ápice en punta culminado con una gran espina

amarilla; brácteas internas de color amarillo claro con nerviaciones violetas. Pedúnculo de largo y espesor medio (Dellacecca et al., 1976).

Características productivas: producción muy temprana o temprana, con inicio a finales de noviembre–diciembre o enero–febrero. Ciclo productivo largo y de producción media.

"Violeto de Provenza"

Zonas de cultivo: Es la principal variedad cultivada en España con capítulos de color violeta. Su destino principal es el mercado francés y su producción está muy centrada en el sur de Alicante y Murcia. Esta variedad se cultiva también en Francia (Provenza), Italia (donde según la zona de cultivo toma el nombre local, por ejemplo: "Violetto Foggiano"), Argelia, Túnez, Egipto, Israel.

Características morfológicas: La planta es de talla pequeña o media y vigor intermedio. La hoja presenta color verde, sin espinas, dimensiones medias, heterofilia elevada por la presencia de hojas de lámina foliar entera en particular en los primeros estadíos vegetativos de la planta y en plantas precoces; las otras hojas son lobuladas. El capítulo es verde con jaspeado rojo intenso inferior al 50% en su base. Forma cónica-alargada y homogeneidad media-buena. Presenta espinas. Esta variedad posee una producción de capítulos media al igual que peso medio de los capítulos (Dellacecca et al., 1976).

Características productivas: producción muy temprana, con inicio en noviembre-diciembre. Ciclo productivo largo.

"Green globe"

Zonas de cultivo: Supone el 90% en las plantaciones en Estados Unidos, englobando el área de la bahía de Monterey. Esta variedad también es cultivada en Egipto.

Características morfológicas: Planta vivaz de hojas grandes verde claro. Los capítulos de "Green Globe" tienen abundantes tonos violeta y son espinosos, además la variedad es algo heterogénea (Gil-Ortega, 1999).

Características productivas: producción temprana y ciclo productivo largo.

"Imperial Star"

Zonas de cultivo: Variedad desarrollada en California con prometedor futuro por su método de propagación sexual, por semillas. Su zona de cultivo se extiende mayoritariamente a Estados Unidos y Egipto.

Características morfológicas: Variedad de porte alto y baja capacidad de rebrotación. El capítulo principal es subesférico, compacto y grande, verde brillante con presencia de antocianos, jaspeado en un 30-45%, sobre todo, en la parte basal del capítulo, apenas espinoso, consistentes y con bastante homogeneidad. Coloración de su corazón similar a la "Blanca de Tudela". Las brácteas exteriores son de color verde claro, grisáceo, brillantes, de ápice apuntado, levemente inciso, pero inerme o terminado en una corta espina curvada (Martínez et al., 2009).

Características productivas: Propagación sexual, por semilla. Es una variedad de multiplicación abierta. Es muy temprana y con buena producción. Presenta producción época estival.

"Tema"

Zonas de cultivo: Variedad desarrollada en Toscana. Su zona de cultivo se extiende mayoritariamente por Toscana y Cerdeña.

Características morfológicas: El capítulo principal es de tamaño medio y campacto, su forma es oval y de color violeta intenso. Las brácteas poseen forma oval y terminadas en punta, consistencia media y apenas presencia de espinas.

Características productivas: Variedad muy productiva capaz de dar una 2 producciones al año. La primera precoz de octubre a diciembre y la segunda tardía de febrero a abril.

"Romanesco C3"

Zonas de cultivo: Su zona de cultivo se extiende principalmente por la región italiana de Lazio aunque es una variedad cuyo cultivo se extiende también por todo el centro-sur de Italia.

Características morfológicas: Se trata de una planta tardía cuya producción se extiende desde enero hasta mayo. Presenta color verde con sombras violáceas. Los capítulos son de diámetro medio-grande presentando una forma subesférica aplastada. Las brácteas son de forma oval con el ápice redondeado e inciso y carente de espinas.

Características productivas: Se trata de una variedad muy productiva, capaz de dar 20-25 capítulos por planta.

3.2.5. Transformación de la alcachofa en producto IV Gama

El diagrama de flujo del proceso de elaboración alcachofas mínimamente procesadas que se indica en la Figura 3 representa un hipótesis del proceso, dado que la mayor parte de los pasos que componen este diagrama están siendo objeto de estudio en diversos trabajos científicos para su optimización.

Recepción de la materia prima. Los capítulos de alcachofa, cosechados manualmente, suelen llegar a la industria de transformación en cajas de poca capacidad (25 kg). Las alcachofas, salvo exigencias específicas de la industria, se reciben sin el tallo y calibradas.

Prerrefrigeración y conservación frigorífica. En caso de no ser elaboradas inmediatamente, tienen que almacenarse en cámaras frigoríficas. En el trabajo realizado por Ricci (2012) se pone de manifiesto el gran impacto que la temperatura y el tiempo de almacenado previos a las operaciones de corte tienen sobre la calidad de la alcachofa

IV Gama. El autor sugiere que temperaturas de conservación superiores a los 12ºC inducen la aceleración de la senescencia en las alcachofas con la aparición de tejidos pubescentes rojizos. Además, los autores indican que temperaturas de 0ºC podrían causar efectos beneficiosos en las alcachofas causando el retraso de la aparición del pardeamiento durante la posterior etapa de corte. Debe evitarse el almacenamiento prolongado a temperatura ambiente, ya que la materia prima puede sufrir fermentaciones y pérdidas de consistencia.

Figura 3. Diagrama de flujo del proceso de elaboración de alcachofas IV Gama

Fuente: Elaboración propia

Desbracteado y perfilado. Las alcachofas deben ser desprovistas de las brácteas externas más verdes y duras no comestibles para posteriormente pasar al perfilado, etapa que variará en función del consumo final. En esta operación las alcachofas sufrirán diversos cortes hasta quedar únicamente el corazón de la alcachofa.

Corte. En esta operación se realizan los cortes necesarios a los corazones de alcachofa para su presentación según los formatos de productos IV gama.

Lavado. Operación que contempla la higienización del producto mediante el lavado con una solución higienizante.

Tratamientos antioxidantes. En esta operación se realiza un lavado con solución antioxidante con el objeto de retrasar el efecto del pardeamineto. Esta operación será objeto de estudio en la presente Tesis Doctoral.

Secado: Posteriormente al tratamiento, debe eliminarse la humedad sobre la superficie del producto mediante la fase de secado.

Envasado. Las alcachofas tratadas y secas se envasan en aire o atmósfera modificada. El efecto de distintas concentraciones de CO_2 sobre alcachofas IV Gama ha sido estudiado por La Zazzera (2011) poniendo de manifiesto que atmósferas con altas concentraciones de CO_2 (25%) puede causar la aparición de manchas oscuras sobre las brácteas resultando perjudicial para la alcachofa, mientras que más bajas concentraciones de CO_2 (5-15%) podrían inducir ligeros beneficios tales como la reducción de la pérdida de peso y menores cambios de color sobre la superficie de corte. Además el autor investigó el efecto de bajas concentraciones de O_2 (1%) que dieron lugar a la aparición de manchas negras sobre las brácteas.

Almacenamiento refrigerado. Tras el envasado, las alcachofas IV Gama se conservan y almacenan a temperaturas entre 0 y 4ºC; siendo muy importante mantener la cadena de frío durante toda la fase de distribución para garantizar el mantenimiento de la calidad.

3.3. LA PATATA COMO PRODUCTO DE LA IV GAMA

3.3.1. Generalidades

La patata (*Solanum tuberosum* L.) pertenece a la familia Solanaceae, la cual también incluye tomate, tabaco, pimiento, berenjena. Es una planta herbácea dicotiledónea y potencialmente es una planta perenne debido a su capacidad de reproducirse por tubérculos.

El tallo, grueso, fuerte, anguloso, con una altura que varía entre 0,5 y 1 m, se origina en las yemas del tubérculo. Las hojas son imparipinnadas; constan de nueve o más foliolos, cuyo tamaño es tanto mayor cuanto más alejados se encuentran del nudo de inserción.

A la vez que tallos aéreos, la planta tiene tallos subterráneos. Los primeros son de color verde, son de sección angular, y entre las axilas de las hojas y los tallos se forman ramificaciones secundarias. Contienen un alcaloide tóxico, la solanina, que puede formarse también en los tubérculos cuando éstos se exponen prolongadamente a la luz. Los tallos subterráneos o estolones que nacen del tallo principal, relativamente cortos, se convierten en su extremidad en tubérculos. El tubérculo de patata se forma en la punta del estolón (rizoma) como una proliferación lateral de tejido de almacenamiento como resultado de una rápida división celular. El tubérculo es la parte que se consume y sirve para almacenar sustancias de reserva; está cubierto por la exodermis, que aparece al romperse la epidermis, que va engrosándose con el tiempo.

Los índices de calidad comercial de la patata incluyen: más del 70 a 80% de los tubérculos bien formados, color brillante (especies rojas, amarillas y blancas), uniformidad, firmeza y ausencia de tierra adherida, libre de daño por golpes (manchas negras o shatter-bruising), abrasiones, roturas de crecimiento, brotación, daños por insectos, cancro negro por *Rhizoctonia* (Rhizoctonia Black Scurf), pudriciones, reverdecimiento u otros defectos (Suslow y Cantwell, 2002).

En la patata, como en cualquier producto hortofrutícola, los procesos metabólicos de los tejidos vegetales prosiguen tras la recolección; en la medida que la integridad de las células y la de su metabolismo se preserve, se prolongará la vida útil de la patata y la de sus atributos de calidad. Se trata de un producto poco perecedero con una vida útil poscosecha de unas 8-16 semanas (Kader, 1990, 2002).

La intensidad respiratoria de las patatas y la producción puede observarse en la Tabla 4.

Tabla 4. Actividad respiratoria y producción de calor de la patata a diferentes temperaturas

Parámetros	Temperatura (ºC)			
	5	10	15	20
Respiración (ml CO2/kg h)	6-8	7-11	7-16	9-23
Producción calor (Kcal/t/día)	1098-2806	854-1952	854-1342	732-976

Fuente: Elaboración propia a partir de Suslow y Cantwell (2002).

La tasa respiratoria de las patatas durante la fase de latencia es muy baja lo que favorece su conservación. Sin embargo, la conservación y acondicionamiento de los tubérculos de patata están influenciados por el estado de madurez del mismo. Así, los tubérculos de patata inmaduros son más susceptibles a daños mecánicos y pueden presentar altas tasas de respiración. Las temperaturas más bajas y/o el incremento en el movimiento del aire son métodos efectivos para reducir los daños ocasionados por un incremento de la respiración. Los tubérculos de patata son poco sensibles al etileno externo pero bajos niveles de éste pueden retrasar la brotación durante el almacenamiento de los tubérculos.

Inmediatamente después de la cosecha, las patatas deben conservarse a 10-16ºC y alta humedad relativa (90-95% HR) para facilitar la curación de los tubérculos y evitar así, pudriciones y pérdidas de peso (Smith, 1987). Este proceso estimula el crecimiento de la peridermis, lo cual facilita la curación de heridas, y su engrosamiento, lo cual reduce las pérdidas de peso y brotaciones. Posteriormente a este periodo de curación, se ha observado que a bajas temperaturas (4-8ºC) se retrasan los cambios y la pérdida de turgencia que ocurren en las patatas conservadas (Nourian et al., 2003).

Durante la conservación de las patatas ocurren diversos cambios que variarán según las condiciones de conservación y la variedad de patata. Las bajas temperaturas inhiben la formación de brotes pero se produce la transformación de almidón en azúcares lo que da lugar en ocasiones a cambios de color (Nourian et al., 2003).

Según Suslow y Cantwell (2002) las causas más evidentes de deterioro de las patatas son los desórdenes fisiológicos tales como:

- Corazón negro (black heart): Ocurre en condiciones de flujo restringido de aire y altas tasas respiratorias. Los tubérculos conservados a temperaturas superiores de 15°C (rápidamente sobre 20°C) desarrollan una decoloración parda interna, la cual eventualmente llega a ser negra. Bajo estas condiciones, en el interior del tubérculo se produce falta de oxígeno.

- Mancha negra (black spot). Responsable de pérdidas significativas en postcosecha, particularmente en respuesta a la sobre-fertilización con nitrógeno, baja disponibilidad de potasio, riego irregular y otras prácticas precosecha. Se forman compuestos incoloros en el tejido vascular justo debajo de la piel durante el almacenamiento. Después de un daño severo o corte, el tejido afectado se torna rojizo, luego llega a ser azul y tras 24 a 72 horas cambia a negro. La severidad se incrementa con el tiempo. Las variedades difieren significativamente en la susceptibilidad y manifestación de los síntomas.

- Daños por frío. El almacenamiento a temperaturas cercanas a 0°C (32°F) durante unas pocas semanas puede dar lugar a ua decoloración caoba del tejido interno en algunas variedades. Para inducir la presencia de daños por frío en tubérculos de patata, el tiempo de almacenamiento tiene elevado.

- Reverdecimiento (greening). La exposición a luz brillante durante el manejo postcosecha, o períodos más largos (1 a 2 semanas) con luz de baja intensidad, puede resultar en el desarrollo de clorofila en el tubérculo de patata, el cual es anatómicamente un tallo modificado. Asociado con el

reverdecimiento, se producen glicoalcaloides amargos y tóxicos tales como la solanina. La solanina también se produce en respuesta a golpes, heridas (incluyendo el procesado en fresco seguido de almacenaje), y durante la brotación. Los glicoalcaloides son estables al calor y son afectados mínimamente por el cocinado.

- Mancha parda interna (internal brown spot). Sectores o manchas de color negro o pardo-rojizo de textura corchosa y seca. El manejo irregular del riego y/o amplias fluctuaciones de la temperatura inducen la deficiencia en la absorción del calcio, normalmente en el desarrollo temprano del tubérculo. Una disponibilidad de agua irregular puede también resultar en corazón hueco (hollow heart), una cavidad corchosa en el centro del tubérculo.

- Daños mecánicos. La cosecha, el embalaje y el manejo deben ser hechos con gran cuidado para prevenir daños en la piel turgente de los tubérculos la cual es altamente sensible y delgada. El aplastamiento, golpes por presión, manchas pardas y tubérculos destrozados, son defectos comunes y pueden conducir a la pérdida de agua, arrugamiento y pudriciones.

- Mancha parda (brown spot). Decoloración justo por debajo de la capa interna de la superficie, la cual es resultado de golpes o manejo no adecuado.

- Daños por congelación**.** El daño por congelación aparece a partir de los -0,8°C. Este daño da lugar a una apariencia de tejido embebido en agua, vidriosidad y desorganización del tejido al descongelarse. Un leve daño por congelación puede resultar en daño por frío.

Otra importante fuente de pérdidas en la postcosecha de tubérculos de patata suele ser la causada por las enfermedades particularmente en combinación con un manejo no adecuado y un pobre control de la temperatura. Tres enfermedades bacterianas y un gran número de hongos son responsables de las pérdidas en postcosecha. Los más importantes patógenos bacterianos y hongos que causan pérdidas en transporte, almacenamiento y a nivel de consumidor son: Pudrición blanda bacteriana (*Erwinia carotovora* subsp. *carotovora* and subsp. *atroseptica*), *Ralstonia* (ex

Pseudomonas, ex *Burkholderi*) *solanacearum*, *Phytophthora infestans* (fuego tardío), pudrición por *Fusarium* (*Fusarium* spp.), Pudrición rosa (*Phytophthora* spp.), y Pudrición acuosa (*Pythium* spp.). Las enfermedades ocasionalmente serias de tubérculos inmaduros incluyen Ojo rosa (*Pseudomonas fluorescens*) y Moho gris (*Botrytis cinerea*).

3.3.2. Producción de patata

El mercado mundial de la patata ha sufrido cambios constantes desde finales de la década de los 90 del siglo anterior, ya que hasta entonces Europa tenía la primacía. Ahora es China, el líder mundial con una producción en 2010 de caso 75 millones de toneladas, del total de 324 millones de toneladas que se produjeron en el mundo. Por orden de importancia en toneladas de patata producidas le siguen la India con 36.577.300 t, Federación Rusa 21.140.500 t, EE.UU. 18.337.500 t y Alemania con 10.201.900 toneladas (FAOSTAT, 2012).

España es un país deficitario de patatas. Según datos del anuario de estadística del 2010 se importaron 722 millones de toneladas de patata. Aporta a la producción mundial 2.277.900 toneladas siendo Castilla y León la comunidad autónoma española con mayor producción de patata con 876.217 t, seguida por Galicia con 498.651 t y Andalucía con 333.687 t (MAGRAMA, 2011).

3.3.3. Calidad de la materia prima

3.3.3.1. Características físicas de la patata

La calidad del tubérculo de patata está relacionada con diversos factores tales como: morfología, estructura y composición química, siendo ésta última la que determinará la calidad nutricional, sensorial y de procesado de la patata (Burton, 1966; Sanderson y White, 1982). De todos los factores que afectan la calidad del tubérculo, los más importantes son: el medioambiente durante el crecimiento del cultivo, la variedad y las prácticas de cultivo empleadas (riego, fertilización, uso de productos químicos). Según Gray y Hughes (1978), la calidad y el valor nutricional de los tubérculos de patata en el momento de la cosecha es el resultado de los efectos de los

factores culturales, varietales y medioambientales durante el desarrollo del cultivo de la patata. La calidad de los tubérculos de patata asociada a su morfología y apariencia externa comprende características tales como el tamaño del tubéruculo, la forma, espesor y apariencia de la piel, profundidad de los ojos, color de la pulpa y de la piel, y verdeamiento ("greening"). Entre las características físicas del tubérculo destacan: forma del tubérculo, profundidad de los ojos, color y textura de la piel y, color de la pulpa de la variedad (Arvanitoyannis et al., 2008).

La forma de los tubérculos varía desde completamente alargada como es el caso de "Spunta" hasta redonda como la "Kennebec", aunque la mayoría tienen una forma ovalada o cilíndrica; la forma del tubérculo condiciona en muchos casos el uso de la variedad, sobre todo, en la transformación industrial (Galdón, et al., 2012). En cuanto a la profundidad de los ojos, se buscan variedades ojos superficiales ya que facilitan el pelado y la preparación, aunque todavía se usan variedades de ojos profundos como la "Red Pontiac". Respecto al color de la piel, éste es debido a la presencia de pigmentos en las células del peridermo; el color del pigmento varía desde el amarillo más o menos claro y uniforme de la variedad en "Monalisa" hasta el violeta oscuro de la "Vitelotte Noire", pasando por el rosa pálido de "Turia" y el rojo de "Red Pontiac"; incluso hay variedades que tienen tubérculos bicolores con piel de color amarillo y la parte cercana a los ojos roja, como es el caso de la variedad "Picasso". La textura de la piel va desde lisa a áspera, jaspeada o rugosa. Por último, en cuanto al color de la carne, éste presenta una amplia gama de coloraciones, desde el blanco de "Kennebec" o "Red Pontiac" al violeta oscuro de "Vitelotte Noire" pasando por el amarillo más o menos intenso. Cada zona o mercado prefiere un tipo de color tanto de piel como de carne.

El uso para el que estarán destinados los tubérculos marcará las características de calidad los mismos, mientras que la aceptación de la materia prima está determinada principalmente por el tamaño, la forma y la buena apariencia visual de los tubéruculos; siendo la calidad del producto procesado evaluada en términos de color, sabor, olor y textura. La uniformidad de tamaño, forma y composición de la materia prima es esencial para la obtención de productos de alta calidad y por este motivo existen rígidas espcificaciones para la patata que se usa en industria. En España, las espcificaciones al respecto se contemplan la Orden del MAPA de 6 de julio de 1983, por la que se aprueba la Norma de Calidad para patata de consumo destinada al mercado interior (modificada

por Orden de 29 de octubre de 1986) recoge las características relativas a calidad, calibre, presentación y etiquetado que deben reunir las patatas (BOE, núm. 166 de 13 de julio de 1983).

3.3.3.1. Composición nutricional de la patata

El tubérculo de patata se considera una parte del tallo de la planta que se ha adaptado para almacenar reservas y para la reproducción. El tubérculo se forma en el extremo del estolón como consecuencia de la acumulación de reservas que se producen por el rápido desarrollo y división celular. El tipo y la cantidad de las sustancias que constituyen el tubérculo son variables y están muy relacionadas con la variedad y con las condiciones de crecimiento (González, 2000; Thybo et al., 2006).

Aunque la patata es rica en carbohidratos también posee cantidades significativas de otros nutrientes tales como proteínas, minerales (hierro) y vitaminas (complejo B y vitamina C) (Augustin, 1975; McCay et al., 1975; Salunkhe et al., 1991).

Tabla 5. Composición nutricional de la patata (100 g peso fresco)

Agua (g)	79,34	Fósforo (mg)	57
Energía (Kcal)	77	Zinc (mg)	1,07
Carbohidratos (g)	17,47	Folatos (µg)	16
Proteína (g)	2,02	Niacina (mg)	1,054
Lípidos Totales (g)	0,09	Vitamina B-6	0,295
Fibra (g)	2,2	Riboflavina (mg)	0,032
Sodio (mg)	6	Tiamina (mg)	0,08
Potasio (mg)	421	Vitamina A (IU)	7
Calcio (mg)	12	Vitamina C (mg)	19,7
Hierro (mg)	0,78	Vitamina E (mg)	0,01
Magnesio (mg)	23	Vitamina K (µg)	1,9

Fuente: USDA, 2013.

Los datos aportados en la Tabla 5 tienen un valor orientativo, ya que la composición nutricional o química de la patata varía con la variedad, la conservación, la época de cultivo, tipo de suelo, nutrición pre-cosecha, y método de análisis usado. Según Mondy (2000) la composición media nutricional de la patata viene representada por: agua, 80%; carbohidratos, 18%; proteína, 2%; lípidos, 0,1%, vitaminas, etc., <0,1%.

Los carbohidratos constituyen cerca del 80% del total de sólidos que se encuentran en la patata (Schwimmer et al., 1954). Representan los compuestos de mayor importancia de ésta junto con el agua, siendo el almidón el carbohidrato más representativo y, la sacarosa, fructosa y glucosa los azúcares más importantes en la patata (Schwimmer et al., 1954).

La patata contiene un alto contenido en vitamina C compuesta mayoritariamente por ácido áscórbico. Se ha indicado que el ácido ascórbico juega un papel importante en diferentes aspectos de la nutrición, la salud humana, y la química de los alimentos. Asimismo, protege a las plantas y animales contra el estrés oxidativo inducido por compuestos tóxicos así como por especies reactivas de oxígeno incluyendo los radicales hidroxil y aniones superóxido (Gregory, 1996; Davey et al., 2000). El ácido ascórbico además, se ha indicado que juega un papel importante contra el pardeamiento en alimentos y ha sido indicado por prevenir contra la toxicidad (Hornig et al., 1988).

Las patatas contienen compuestos tóxicos llamados glicoalcaloides (Friedman y McDonald, 1997). Los glicoalcaloides son compuestos nitrogenados que se producen de manera natural en las *Solanáceas* (Carman et al., 1986; Friedman y McDonald, 1997). Los glicoalcaloides tienen un papel importante en los mecanismos de defensa natural contra organismos como hongos, insectos, virus y herbívoros (Ferreira, et al., 1993; Hlywka et al., 1994; Rodríguez-Saona, et al., 1999). Además se ha indicado que los glicoalcaloides son causantes de enfermedades incluso de muertes en humanos y animales (Thomson y Sporns, 1995).

Dependiendo de la variedad de patata, una amplia variedad de ácidos fenólicos (ácido clorogénico, ácido cafeico, ácido ferúlico, ácido coumárico y ácido quínico) y antocianos (derivados de pelargonidina 3-(p-coumaril-ramnosilglucosido)-5 glucósido, peonidina, petunidina y malvidin) se han descrito (Lewis et al., 1998; Rodríguez-Saona, et al., 1998; Lachman, et al., 2005). Los compuestos fenólicos se distribuyen mayormente entre el córtex y la piel de la patata (Reeve et al., 1969). Cerca del 50 % de los compuestos fenólicos se localizan en la piel de la patata y tejidos adyacentes, mientras el resto disminuye su concentración desde fuera hacia el centro del tubérculo (Hasegawa et al., 1966). Los compuestos fenólicos tienen un importante papel en la

alimentación humana y en los procesos de pardeamiento tal y como se ha descrito en el caso de alcachofa.

3.3.4. Variedades

Debido a que su producción abarca todo el año, la caracterización agronómica de este tubérculo se realiza en función de la época de recolección, distinguiéndose entre:

- Patata extra-temprana y temprana (del 15 de enero al 15 de junio).
- Patata de media estación (del 16 de junio al 30 de septiembre).
- Patata tardía (del 1 de octubre al 14 de enero).

El número de variedades disponibles en el mercado es muy abundante y con propiedades organolépticas parecidas. Su importancia además, es muy dependiente de la zona de consumo y del destino de la producción. A continuación, se detallan las variedades de mayor relevancia en nuestro País clasificadas según época de recolección (Illescas y Bacho, 2005):

- Variedades extratempranas:

  "Jaerla"

  Su zona de cultivo se extiende además de nuestro País por, Bélgica, Italia, Holanda, Rumanía, Panamá, Argelia y Líbano.

  Es una variedad de forma oval redondeada, piel amarilla y lisa, carne amarilla, ojos bastante superficiales y de piel oscura.

  El rendimiento de esta variedad es mediano presentando tubérculos de tamaño grande o muy grande con un contenido de materia seca muy bajo.

  "Monalisa"

  La planta es alta, estructura del follaje de tipo ramificado; tallos semierguidos, coloración antociánica de mediana a ligera; hojas grandes, de color verde oscuro a verde; silueta semiabierta; inflorescencias de numerosas a bastante numerosas, coloración antociánica, ausente o muy débil de la cara interna del corola de la flor. Los tubérculos son de forma oval; piel amarilla

y muy lisa; carne bastante amarilla; ojos superficiales. Los brotes son medianos, ovalado, coloración antociánica de fuerte a mediana y pubescencia del brote, de medianamente a poco vellosa; yema terminal, de mediana a pequeña y coloración antociánica débil; puntas radicales bastante numerosas.

El rendimiento de esta variedad es de mediano a alto presentando tubérculos de tamaño grande y con un contenido de materia seca bajo.

- Variedades tempranas:

"Red Pontiac"

Su zona de cultivo se extiende por España, Bélgica, Canadá, Holanda, Panamá y Estados Unidos.

Redonda, piel roja, semilisa, carne blanca, ojos semiprofundos.

"Kondor"

La planta es de talla alta a mediana, estructura del follaje de tipo intermedio; tallos semierguidos, coloración antociánica de fuerte a mediana; hojas grandes, de color verde oscuro a verde; silueta semiabierta; inflorescencias de numerosas a bastante numerosas, coloración antociánica de muy fuerte a fuerte, de la cara interna del corola de la flor. Los tubérculos de forma oval alargada de forma; piel roja y lisa a bastante lisa; carne amarilla clara; ojos semiprofundos. Los brotes son grandes, coniformes, coloración antociánica fuerte y pubescencia del brote velloso; yema terminal, de grande a mediana y coloración antociánica mediana; puntas radicales bastante numerosas.

El rendimiento de esta variedad es muy alto, presentando tubérculos muy grandes con contenido en materia seca bajo.

"Spunta"

La planta es alta, estructura del follaje de tipo intermedio; tallos de semierguidos a erguidos, coloración antociánica mediana; hojas de grande a mediana, de color verde oscuro; silueta semiabierta; inflorescencias de

numerosas a bastante numerosas, coloración antociánica ausente o muy débil de la cara interna de la corola de la flor. Los tubérculos son de forma alargada; piel amarilla y lisa; carne amarilla clara; ojos muy superficiales. El brote es grande, en forma de cilindro grueso, coloración antociánica fuerte y pubescencia del brote de velloso a medianamente velloso; yema terminal de grande a mediana y coloración antociánica, de mediana a débil; puntas radicales de numerosas a bastante numerosas.

El rendimiento de esta variedad es alto, presentando un tamaño de tubérculo muy grande y un contenido de materia seca alto.

"Liseta"

La planta es de alta a mediana, estructura del follaje de tipo foliar; tallos de extendidos a semierguidos, coloración antociánica ausente o muy débil; hojas de grande a mediana, de color verde a verde claro; silueta de abierta a semiabierta; inflorescencias de muy poco numerosas a ausentes, coloración antociánica ausente o muy débil de la cara interna de la corola de la flor. Los tubérculos son de forma oval alargada; piel amarilla y de lisa a bastante lisa; carne amarilla clara; ojos superficiales. Brote grande, en forma de cilindro grueso, coloración antociánica débil y pubesenca del brote velloso; yema terminal pequeña y coloración antociánica de débil a muy débil; puntas radicales de numerosas a bastante numerosas.

El rendimiento de esta variedad oscila entre medio y alto presentando un tamaño grande de tubérculos y un contenido de materia seca mediano.

"Agata"

La planta es corta, estructura del follaje de tipo foliar; tallos extendidos, coloración antociánica ausente o muy débil; hojas de grande a mediana, de color verde a verde claro; silueta de semiabierta a cerrada; inflorescencias poco numerosas, coloración antociánica ausente o muy débil de la cara interna de la corola de la flor. Los tubérculos tienen forma oval; piel amarilla

y lisa a bastante lisa; carne amarilla clara; ojos superficiales. El brote es mediano, en forma de cilindro grueso, coloración antociánica, de débil a muy débil y pubescencia del brote poco velloso; yema terminal mediana y coloración antociánica débil; puntas radicales bastante numerosas.

El rendimiento de esta variedad es alto, presentando un tamaño de tubérculos grande y un contenido de materia seca bajo.

"Agria"

La planta es alta con estructura del follaje de tipo intermedio; tallos de semierguidos a erguidos, coloración antociánica mediana; hojas grandes, de color verde; silueta de abierta a semiabierta; inflorescencias numerosas, coloración antociánica ausente o muy débil de la cara interna de la corola de la flor. Los tubérculos son de forma oval alargada; piel amarilla y lisa a bastante lisa; carne amarilla; ojos superficiales. El brote es grande, en forma de cilindro grueso, coloración antociánica, de muy fuerte a fuerte y pubescencia del brote, de muy velloso a velloso; yema terminal mediana y coloración antociánica, de muy fuerte a fuerte; puntas radicales de bastante numerosas a poco numerosas.

El rendimiento de esta variedad es muy alto, presentando un tamaño de tubérculo grande y un contenido de materia seca bueno.

"Caesar"

La planta es alta con estructura del follaje de tipo intermedio; tallos de semierguidos a erguidos, coloración antociánica mediana; hojas grandes, de color verde; silueta de abierta a semiabierta; inflorescencias numerosas, coloración antociánica ausente o muy débil de la cara interna de la corola de la flor. Los tubérculos son de forma oval alargada; piel amarilla y lisa a bastante lisa; carne amarilla; ojos superficiales. Los brotes son grandes, en forma de cilindro grueso, coloración antociánica, de muy fuerte a fuerte y pubescencia del brote, de muy velloso a velloso; yema terminal mediana y

coloración antociánica, de muy fuerte a fuerte; puntas radicales, de bastante numerosas a poco numerosas.

El rendimiento de esta variedad oscila entre medio y alto presentando un tamaño de tubérculo grande y un contenido de materia seca alto o mediano.

3.3.5. Transformación de la patata en producto IV Gama

El diagrama de flujo del proceso de elaboración patata mínimamente procesadas que se indica en la Figura 4 representa un hipótesis del proceso, dado que la mayor parte de los pasos que componen este diagrama están siendo objeto de estudio en diversos trabajos científicos para su optimización.

Recepción de la materia prima. Las patatas procedentes de las zonas agrícolas de producción llegan a la industria en vehículos adaptados para tal fin, recibiéndose la práctica totalidad de la materia prima en yumbos.

Almacenamiento. Las partidas de patatas, una vez realizado el control de calidad correspondiente e identificadas, son almacenadas en cámara frigorífica para su conservación.

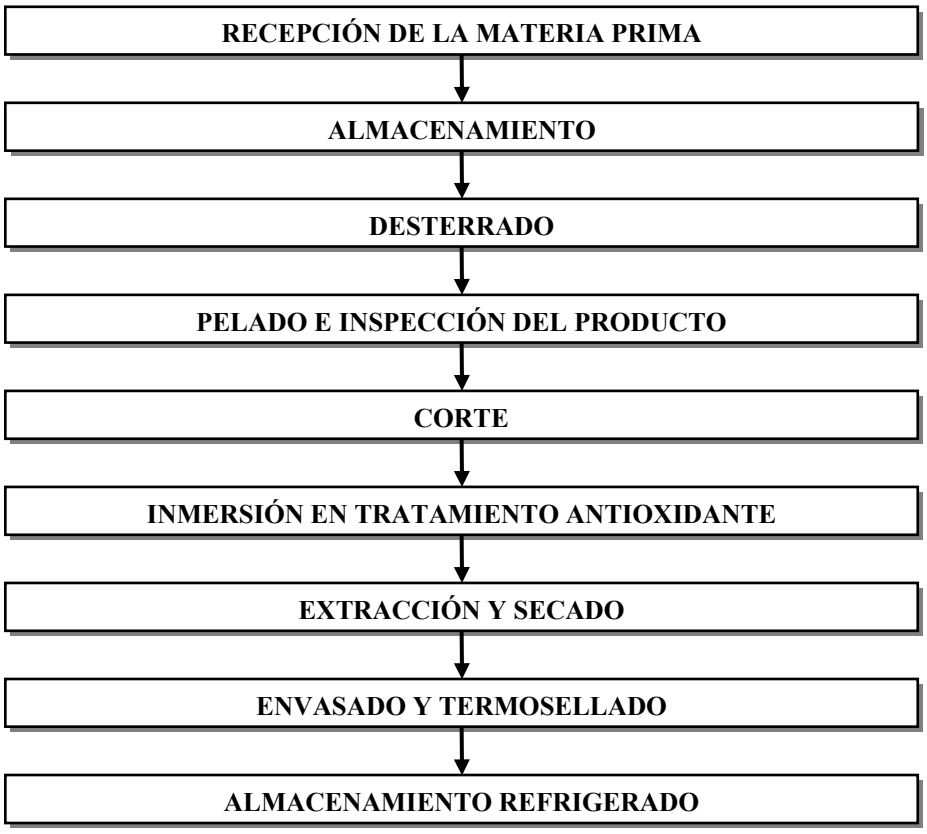


Figura 4. Diagrama de flujo del proceso de elaboración de patatas IV gama

Fuente: Elaboración propia.

Desterrado. Operación que se realiza en función de las necesidades del cliente. Las patatas del almacén se descargarán en las tolvas de recepción que se encuentran al inicio de la línea de manipulación, donde serán sometidas a un proceso de eliminación de tierra.

Pelado. El pelado de las patatas se realiza mediante equipos automáticos provistos de cuchillas. Tras el pelado se realiza una inspección del producto en el que se retirarán las unidades con golpes y cortes, realizándose un repaso por si quedaran trazas de piel. Posteriormente, son dirigidas hacia la zona de corte o a los baños donde se realizan los tratamientos, en el caso de que la patata vaya a comercializarse entera.

Corte. Se realiza mediante una cortadora automática que permite seleccionar el tipo de corte que se desea realizar. Al salir de la cortadora, las patatas pasan a un bombo desfeculador en el que se enjuaga la fécula que se desprende durante el corte. Las patatas envasadas enteras no pasan por esta etapa.

Inmersión en tratamiento antioxidante. Las patatas enteras o cortadas son sumergidas en una solución que prolongará su vida útil. El tiempo que permanecen en contacto con la solución depende de la variedad, y del tipo de corte, así como del tipo de envasado. En la industria existe un uso extendido de los sulfitos como agentes antioxidantes. Los sulfitos pueden provocar asma (Peroni y Boner, 1995) y sabores desagradables así como una significativa reducción del valor nutricional de las patatas IV Gama, lo que ha motivado numerosas investigaciones tendentes a encontrar un sustitutivo eficiciente a estos compuestos. Diferentes inhibidores del pardeamiento han sido investigados para reducir el pardeamiento de frutas y hortalizas tales como ácido cítrico (Gunes y Lee, 1997; Sapers et al., 1997), ácido ascórbico, ácido pirofosfatico de sodio (Sapers et al., 1997), compuestos de sulfidrilo (Molnar-Perl y Friedman, 1990; Friedman y Bautista 1995; Gunes y Lee 1997; Rocculi, et al., 2007). La optimización de esta operación ha sido objeto de estudio de la presente Tesis Doctoral cuyos resultados se presentan en el capítulo 5.

Extracción y secado. Tras la etapa de tratamiento y mediante el uso de cintas transportadoras, las patatas serían sometidas a un secado para eliminar parte de la humedad que han adquirido durante la inmersión en el baño de tratamiento.

Envasado y termosellado. A continuación, las patatas se introducirían en el envase y se realizaría el termosellado de los mismos, o termosellado sin vacío en el caso de que sean envasadas sin vacío. El uso de atmósferas modificadas en patata ha mostrado un efecto diferente dependiendo de la concentración de O_2 empleado (Pérez-Trejo et al., 1981; Burton, 1982, 1989; Fonseca et al., 2002).

Almacenamiento refrigerado. Tras el envasado, las patatas IV Gama se conservan y almacenan a temperaturas entre 0 y 4 ºC; siendo muy importante mantener la cadena de frío durante toda la fase de distribución para garantizar el mantenimiento de su calidad.

3.4. FENÓMENOS DE PARDEAMIENTO EN ALCACHOFAS Y PATATAS EXPUESTAS AL CORTE

3.4.1. Causas del pardeamiento

La producción de melanina es la principal responsable del pardeamiento de frutas y hortalizas (Vámos-Vigázó, 1995). El pardeamiento enzimático es común en todo el reino vegetal afectando al color, sabor, valor nutricional y seguridad del alimento (Hurrell y Finot, 1984; Matheis y Whitaker, 1984; Sapers et al., 1994).

En algunos casos el pardeamiento presente en frutas y hortalizas es de naturaleza no enzimática. El pardeamiento en esos casos se atribuye a reacciones de autooxidación de compuestos fenólicos (Singleton y Rossi, 1965).

La mayor parte de las estrategias para controlar el pardeamiento de las superficies expuestas al corte se centran en modular la actividad de la polifenoloxidasa (PPO) (Martínez y Whitaker, 1995).

El proceso de pardeamiento enzimático da comienzo con la rotura de membranas en el interior de las células del tejido vegetal (Toivonen, 2004). El estrés mecánico y físico que suele ocasionarse durante la transformación de las materias primas en productos de IV Gama, crea una señal que migra a tejidos adyacentes no dañados e induce a una serie de respuestas fisiológicas (Salveit, 1997). Uno de los cambios más perjudiciales, como respuesta al estrés mecánico y físico, es el que induce el metabolismo fenilpropanoide dando como resultado la acumulación de compuestos fenólicos y el posterior pardeamiento de tejidos. Cuando un estrés físico o proceso de deterioro (respuesta al daño o senescencia) inicia, la compartimentalización de las células comienza a fallar (Marangoni et al., 1996). Como consecuencia a este fenómeno se produce la mezcla de sustratos fenólicos (catequinas, polífenoles) con la polifenol oxidasa y/o fenol peroxidasa (Degl'Innocenti et al., 2005). Así ocurre en patatas IV Gama donde la tasa de pardemiento no depende de la cantidad de enzima asociada con el pardeamiento o con la concentración de sustrato tal y como describen Cantos et al., (2002). En el caso de la alcachofa, la enzima polifenoloxidasa se localiza en el

citoplasma en forma soluble con los sustratos fenólicos de localización vacuolar, desencandenándose tras la descompartimenación celular el proceso de pardeamiento (Lattanzio et., al., 1994; Espín et al., 1997). El pardeamiento de frutas y hortalizas reduce su calidad y es frecuentemente el factor limitante para la comercialización de productos IV Gama (López-Gálvez et al., 1996), presentando gran incidencia en los productos objeto de estudio de esta Tesis Doctoral: alcachofa (Lattanzio et al., 1994) y patata (Matheis et al., 1977; Cantos et al., 2002).

El enzima clave en la regulación de la melanogénesis es la tirosinasa o polifenoloxidasa (monofenol, o-difenol; oxigeno-oxidoreductasa; EC (Enzyme Commission 1.14.18.1; E.C. 1.10.3.1 o PPO) (Kim y Uyama, 2005). Esta enzima tiene dos átomos de cobre en su sitio activo, siendo capaz de catalizar dos tipos de reacción donde el oxígeno molecular está presente: (1) la hidroxilación de monofenoles a o-difenoles (actividad monofenolasa) y (2) la oxidación de o-difenoles a quinonas (actividad difenolasa). La reacción de hidroxilación es relativamente lenta y da como resultado productos no coloreados, mientras la reacción de oxidación es relativamente rápida y dan como resultado a quinonas que son compuestos coloreados (Toivonen y Brummell, 2008). Las o-quinonas son compuestos muy reactivos que llevan a la acumulación de melanina, la cual presenta coloración marrón o negra que se asocia con el "pardeamiento" en los tejidos vegetales. Durante la oxidación de las quinonas suelen generarse radicales libres en la mayoría de los casos. El exceso de radicales libres junto con la luz ultravioleta son causantes del estrés oxidativo que da lugar a cambios de pigmentación (Yasui y Sakurai, 2003).

Las enzimas polifenoloxidasas oxidan los compuestos producidos en la primera fase del metabolismo fenólico. Esta primera fase está constituida por la conversión del amino ácido L-fenilalanina en ácido trans-cinámico mediante la enzima fenilalanina-amonio-liasa (EC 4.3.1.5; PAL). La actividad de la reacción catalizada por la PAL aumenta en respuesta generalmente a los daños mecánicos (estrés de corte) (Salveit, 1989) y a la producción de etileno (Martínez y Whitaker, 1995). Dada la importancia de la actividad de la PAL en el mecanismo de oxidación de los tejidos vegetales, algunos autores sostienen la importancia de la actividad de la PAL como índice potencial de la vida útil en algunos productos IV Gama (Ke y Saltveit, 1986; Hyodo y Fujinami, 1989; Ritenour et al., 1995; López-Gálvez et al., 1996; Degl'Innocenti et al., 2005).

Otra enzima oxidativa importante en el reino vegetal es la peroxidasa (EC 1.11.1.7; POD). Esta enzima se asocia con procesos tales como la lignificación (Prota et al., 1988). POD lleva a cabo la oxidación de un electrón de los compuestos fenólicos en presencia de peróxido de hidrógeno (Dunford y Stillman, 1976). Dada la baja concentración de peróxido de hidrógeno en los tejidos vegetales, se estima que su papel en la oxidación de algunos fenoles es debido a un efecto sinérgico entre PPO y POD (Subramanian et al., 1999).

3.4.2. Factores que influencian las reacciones de pardeamiento de alcachofa y patata

El pardeamiento enzimático requiere de la disponibilidad de cuatro componentes esenciales: oxígeno, enzima, cobre y sustratos apropiados. Estos factores determinan la velocidad de pardeamiento de los tejidos vegetales, que puede tener lugar muy rápidamente, incluso en minutos. Esta velocidad dependerá de factores como la concentración y actividad del enzima, de la cantidad y naturaleza de los componentes fenólicos, pH, temperatura, actividad de agua y de la cantidad de oxígeno disponible en el entorno del tejido vegetal. Otros factores intrínsecos que intervienen en la intensidad del pardeamiento son: la especie, la variedad, y el estado fisiológico del producto vegetal (Ahvenainen, 1996).

Oxígeno. La reacción catalizada por la PPO tiene lugar en presencia del oxígeno, es por ello que reduciendo la concentración de este gas, por sustitución del aire en el interior de los envases, podrían reducirse los cambios de color aunque no eliminarlos totalmente. La precisión en el envasado de los productos IV Gama es esencial para asegurar la correcta concentración de oxígeno. Niveles altos de oxígeno en los envases pueden llevar al pardeamiento de las superficies cortadas, mientras niveles demasiado bajos pueden dar origen a un metabolismo anaeróbico con producción de malos olores y sabores (Mateos et al., 1993; Gorny et al., 2002; Angós et al., 2008). Laurila et al., (1998) encontraron que las atmósferas modificadas por si solas, confieren algunos beneficios pero no mantienen la calidad visual de las patatas IV Gama cortadas en rodajas. En alcachofa IV gama se ha observado que el uso de atmósferas del 25%

CO_2 pueden resultar perjudiciales para su conservación mientras que concentraciones del 5-15% de CO_2 podrían generar ligeros beneficios (La Zazzera et al., 2012).

El material de envasado tiene gran relevancia en el mantenimiento de la atmósfera alrededor del producto cortado. Habitualmente los materiales de envasado utilizados son plásticos de derivados petroquímicos, aunque en la actualidad existe una tendencia a sustituir éstos por plásticos con mayor respeto por el medio ambiente y materiales biodegradables (Tharanathan, 2003).

Enzima. La PPO del reino vegetal suele presentar un óptimo de pH entre 6,0-6,5; así, podría pensarse que a pH inferiores a 4,5 se pueden obtener niveles más bajos de actividad enzimática (Whitaker, 1994). Autores como Richardson y Hyslop (1985) afirman que a pH inferior a 3,0 podría darse la inactivación de la PPO de manera irreversible e incluso Nicolas et al., (1994) afirman que a esos valores de pH su actividad es del 40%. En el caso de alcachofa el óptimo de actividad de la PPO se obtiene a pH entre 5,0 y 8,0 variando según los diferentes sustratos (Lattanzio et al., 1994) mientras que en patata, Cantos et al., (2002) sitúan el pH óptimo entre 5,25 y 5,75 para la actividad de la PPO, dependiendo de la variedad.

Distintos los autores (Ahvenainen, 1996; García y Barrett, 2002) sugieren para retrasar el pardeamiento, la disminución del pH mediante la immersión del producto en soluciones de ácidos orgánicos. Esta metodología forma parte de los métodos químicos utilizados para retrasar el pardeamiento mediante el uso diferentes tipos de aditivos tales como agentes reductores, acidulantes, quelantes y acomplejantes o compuestos que actúan directamente inhibiendo la PPO.

Los aditivos más utilizados para retrasar el pardeamiento son:

- Ácido cítrico: es el atioxidante más utilizado, actúa como agente quelante acidulante en la inhibición de la PPO. Giménez et al., (2003) utilizaron con éxito ácido cítrico para reducir el pardeamiento en alcachofas.

- Ácido ascórbico: este antioxidante tiene tanto acción acidulante como reductora, reconvirtiendo las quinonas en fenoles. El ácido ascórbico actúa

en particular sobre las benzoquinonas y tiene un efecto directo sobre la PPO además de bajar el pH (Golan-Goldrish et al., 1992; Whitaker, 1994). El ácido ascórbico actúa reduciendo las quinonas a sus o-difenoles precursores, previniendo la formación de pigmentos (Walker, 1975). Lattanzio et al., (1989) investigaron el uso de soluciones al 1% de ácido cítrico y ascórbico en alcachofas como retardantes del pardeamiento obteniendo escasos beneficios. Sin embargo las acciones de los ácidos ascórbico y cítrico tienen acción temporal (Özoglu y Bayindirli, 2002).

- Cisteína: es un inhibidor de la PPO muy efectivo (Eidhin et al., 2005); sin embargo, su modo de acción es complejo. Durante la oxidación la cisteína atrapa las o-quinonas formando productos no coloreados, los cuales son inhibidores competitivos de la PPO (Richard-Forget et al., 1992).

  Diferentes estudios han evaluado la eficiencia de la cisteína como agente anti-pardeamiento en hortalizas y frutas de IV Gama (Dorantes-Álvarez et al., 1998; Guerrero-Beltrán et al., 2005; Rojas-Graü et al., 2006), ya sea aplicada sola o junto con otros ácidos orgánicos, mostrando diferentes resultados. Algunos autores (Gorny et al., 2002; Vilas-Boas y Kader, 2006; Rocculi et al., 2007; Larrigaudière et al., 2008) han puesto de manifiesto efectos negativos de la cisteina sobre la apariencia y el metabolismo de los productos IV gama.

- El ácido etilendiaminotetraacético (EDTA), es un agente quelante que puede crear complejos con el cobre presente en el enzima, inhibiendo así su actividad. Este agente se ha utilizado en patatas (Cherry y Singh, 1990; Dennis, 1993) y lechuga Iceberg (Castañer et al., 1996), ya sea solo o junto con otros inhibidores.

- El SporixTM, es un agente quelante conocido como sustitutivo del ácido polifosfórico ha demostrado ser un buen inhibidor del pardeamiento de muchas frutas y hortalizas (Gardner et al., 1991; Sapers et al., 1998).

- El cloruro de sodio es un inhibidor débil del pardeamiento. Actúa bajando el pH. Algunos autores han destacado las grandes concentraciones de cloruro de sodio necesarias para inhibir la PPO lo que podría comprometer el sabor del producto (Mayer y Harel, 1991).

- Los tratamientos a base de calcio empleados para mejorar la firmeza de los tejidos han sido también reconocidos como reductores del pardeamiento (Drake y Spayd, 1983; Hopfinger et al., 1984; Bolin y Huxsoll, 1989). Se ha demostrado que el uso del cloruro de calcio ($CaCl_2$) junto con soluciones de ácidos orgánicos, además de tener efecto sinérgico en el mantenimiento del color, preserva la estructura de los productos tratados, evitando pérdidas de consistencia en el periordo de conservación (Rosen y Kader, 1989; D'Amato et al., 2000; Massantini et al., 2000).

- El 4-hexyl resorcinol (4HR) es uno de los inhibidores más recientemente descubiertos (McEvily et al., 1991). Este compuesto interacciona con la PPO imposibilitando que ésta catalice la reacción de pardeamiento (Lambrecht, 1995). Su utilización ofrece ventajas respecto a los sulfitos en los alimentos, ya que tienen acción específica de inhibición, incapcidad de decolorar los pigmentos formados además de una mayor estabilidad química (McEvily et al., 1992). Por sus propiedades no tóxicas, no mutágenas y no cancerígenas (McEvily et al., 1992), el 4-HR está obteniendo bastante aceptación en la industria alimentaria. McEvily et al., (1991) han estudiado su aplicación en patatas y manzanas este producto obteniendo buenos resultados por inhibición directa de la PPO.

Gran parte de los counsumidores prefieren productos sin conservantes (Bruhn, 1995), y los productos IV Gama se perciben como productos tratados mínimamente por lo que muchos productores prefieren no utilizar aditivos químicos que pudieran cambiar la percepción de "producto natural" tendiendo por ello a utilizar tratamientos lo más naturales posible para inhibir el pardeamiento enzimático tales como la aplicación de zumos naturales y ácidos orgánicos (Son et al., 2000).

Algunos estudios han mostrado la posibilidad de utilizar "plásticos comestibles" para el tratamiento superficial de los productos mínimamente procesados (Erbil y Muftugil, 1986), en sustitución al uso de atmósferas modificadas. La función principal de los plásticos comestibles es la de limitar y regular los intercambios gaseosos entre el producto y la atmósfera en el interior del envase. Conociendo las cinéticas de ese fenómeno, la composición inicial de la atmósfera y la permeabilidad del envase, es posible preveer la evolución de las características de la mezcla gaseosa en el espacio de cabeza y por tanto, hacer que se mantenga un nivel de composición óptimo para el producto durante la vida útil. Existen diversos tipos de "cubiertas comestibles" a base de celulosas, caseínas, zeínas, proteínas de soja, hidrocoloides, quitosan, polisacáridos micróbicos, ésteres, etc. En alcachofas, Massingnan et al., (2005) han observado pérdidas de peso muy ligeras realizadas tras 4 y 8 días de frigoconservación a 3ºC, en corazones de alcachofa tratados con diferentes coberturas comestibles y envases plásticos MRX. Las diferentes coberturas no mejoraron el aspecto exterior de las alcachofas mientras que el envasado en atmósfera modificada permitió reducir la deshidratación y los daños fisiológicos en el control no tratado. Del Nobile et al., (2009) han estudiado en alcachofa el efecto del ácido cítrico combinado con cloruro de calcio o alginato de sodio durante 6 días de conservación observando mejorías respecto al control.

Sustrato. Los fenoles son los constituyentes naturales, responsables del color y del sabor de los productos hortofrutícolas. El contenido de compuestos fenólicos en los tejidos vegetales varía en función de la especie, de la variedad, del órgano de la planta considerado, del estadío fisiológico y de las condiciones pedoclimáticas. Numerosos estudios han puesto de manifiesto que las propiedades saludables de la alcachofa (inhibición de la biosíntesis del colesterol, movilización de las reservas energéticas, poder hepato-protectivo, favorecimiento de la circulación sanguínea, prevención de enfermedades cardiovasculares, etc.,) dependen esencialmente de sus propiedades antioxidantes, las cuales se deben a la fracción polifenólica constituida principalmente de ácidos mono- y di-cafeilquínicos y de los flavonoides. Los fenoles tienen doble papel ya que tienen tanto actividad antioxidante como constituyen el sustrato en las reacciones de pardeamiento, sobre todo, en presencia de hierro (Lattanzio et al., 1994).

La tendencia al pardeamiento es gran parte cuestión genética, y puede variar entre los cultivares como se ha observado en patatas (Janovitz-Clapp, 1989). Además de las diferencias varietales, dentro de un mismo producto se encuentran diferencias en su composición. Algunos tejidos pueden tener una elevada actividad de la PPO y/o una alta concentración de sustratos fenólicos que, en apropiadas condiciones, llevan a una mayor tendencia al pardeamiento. En las alcachofas, las brácteas internas del corazón de la alcachofa poseen un mayor contendo en polifenoles que las brácteas externas (Lattanzio et al., 1994). En patata, la zona más cercana a la epidermis es la más rica en polifenoles (Reeve et al., 1969). Además, la actividad de la PPO podría variar de manera importante entre cultivares cosechados en la misma época si poseen distinto grado de madurez, siendo los tejidos más jóvenes aquellos con mayor contenido fenólico.

Para seleccionar la variedad a procesar como producto IV Gama, el genotipo es el primer y más importante factor precosecha que debe evaluarse. Las variedades difieren en su carga genética dando lugar a diferencias en el producto fresco tales como el color, sabor, textura, valor nutricional, resistencia a pesticidas y facilidad de procesado entre otras (Beverly et al., 1993). En particular son preferibles variedades:

- con bajos niveles de actividad enzimática (polifenoloxidasas y hemicelulasas) que contribuyan a los procesos de degradación y de pardeamiento, pérdida de consistencia, producción de sustancias volátiles;
- menos sensibles al frío para consentir una mayor flexibilidad en la gestión de las temperaturas y una mejora de la conservación y de la calidad;
- baja estacionalidad, cultivables en diferentes épocas del año para permitir una continuidad de producción en línea con las exigencias de los mercados;
- con buena resistencia genética a las enfermedades que permitan asegurar la integridad del producto evitando, o reduciendo, el uso de fitofármacos y el consecuente acúmulo de éstos en el producto;
- con resistencia a golpes que contribuyan a reducir tanto el nivel de actividad metabólica del vegetal como las vías de acceso y los estímulos a los colonización micróbica de la elaboración.

3.4.3. Valoración del pardeamiento

Los vegetales mínimamente procesados se deterioran más fácilmente que el producto entero del que provienen. Esto es debido a las lesiones ocasionadas durante el proceso productivo, que llevan a cambios físicos y fisiológicos que influencian la calidad del producto (Bretch, 1995; Saltveit, 1997). Aunque otros parámetros como el sabor, la consistencia y el valor nutricional tienen mucho peso en la elección del consumidor, en la fase de compra la elección está basada principalmente en la apariencia externa del producto. Los síntomas visuales del deterioro de los productos IV Gama incluyen el reblandecimiento, la deshidratación por pérdida de agua, los cambios de color (debidos en particular al aumento del pardeamiento oxidativo en las superficies de corte), y las contaminaciones microbiológicas (King y Bolin, 1989; Bretch, 1995).

Algunas de estas características visuales (color, pardeamiento, índice de marchitez) pueden ser medidas instrumentalmente, pero los resultados de estos análisis en la mayor parte de los casos no dan una idea completa del aspecto general del producto. Las propiedades ópticas (color, lucidez, translucidez o turbidez) dependen de la forma (absorbancia, transmisión, reflexión especular, reflexión difusa) con la que el rayo interacciona con la sustancia alimentaria. Las variaciones de color son una importante señal de los cambios cualitativos (Riva, 2003).

La valoración del color puede ser subjetiva u objetiva:

- Subjetiva: se sirve del ojo humano para evaluar el color. Entre las ventajas destacan el hecho de ser mas rápida y sencilla que la valoración objetiva, no necesita instrumentación específica y las cartas colorimétricas o las guías de color pueden ser empleadas como puntos de referencia para describir los colores. Entre sus desventajas se puede señalar que los resultados varían considerablemente por los errores de percepción del ojo humano y, que la cantidad y calidad de la luz pueden influenciar la percepción del color.
- Objetiva: se emplea un instrumento para la valoración del color basándose en la cantidad de luz reflejada sobre la superficie del producto o transmitida a través del producto. Entre sus ventajas de este tipo de valoración destaca el

que presenta menor variabilidad en la medida del color, se pueden medir de manera precisa pequeñas diferencias de color, admite la automatización sobre las líneas de producción y se pueden utilizar unidades portátiles. Las desventajas son que necesita instrumentos específicos con costes elevados, podría ser más lenta que la valoración subjetiva (Mitcham et al., 1996).

Las propiedades ópticas juegan un papel fundamental como anticipo del sabor. Así, la apreciación visual del alimento hoy en día parece paradójicamente más importante que probar la consistencia, masticándolo, o reconociendo sus atributos a través de gusto o del olfato. Aquello que percibimos a través del sentido de la vista resulta discriminatorio por el gusto y el olfato (Riva, 2003). Es por ello que las valoraciones visuales de un producto, adquieren una importancia relevante; de hecho, el análisis de un fruto o de qualquier otro vegetal comienza con el impacto visual del aspecto externo y continua con la valoración del color, la forma, el brillo, la homogeneidad de la presentación. Estos factores que influencian la elección visual y que junto con otro análisis externo, el olfativo, determinan la elección del consumidor. El análisis continúa con la cata, durante la cual se perciben los sabores y los aromas. El objetivo del panel de cata es el de reflejar las preferencias y gustos de un consumidor-tipo.

El procedimiento de medida del color utiliza colorímetros de reflexión, instrumentos derivados de los espectrofotómetros de absorción en el visible para medir en reflexión (Toyotsu-cho y Suita-shi, 1997).

El colorímetro tristímulo es el instrumento más difundido para la medida del color y entre las diferentes escalas, la más utilizada es la escala CIE L*a*b*. De estos parámetros y en particular del índice a*(índice de rojo) e índice b* (índice de amarillo) se obtienen los parámetros de Saturación (C*) y de Ángulo de Tinta o Hue angle (h*) en radianes o en grados.

La luminosidad L* (perpendicular al plano a*b*) va de 0 (luminosidad nula) a 100 (luminosidad máxima, correspondiente a un blanco elegido como referencia); la coordenada a* da el valor de rojo cuando es positiva y el verde cuando es negativa;

mientras la coordinada b* da el valor de amarillo cuando es positiva y el azul cuando es negativa. Los límites de a* y b* se encuentran entre +127 y -128.

El color percibido se define como el ángulo de tinta medido en radianes, es decir, el ángulo formado entre la dirección en el que se lee la saturación y el eje del valor a*

$$\text{Ángulo de tinta} = arctg \frac{b^*}{a^*}$$

Una vez definida una tinta, la Saturación de un punto localizado sobre la línea de tinta, está definida por la distancia entre el origen de los ejes a*b* y el mismo punto, numéricamente se expresa como:

$$\text{Saturación} = \sqrt{a^{*2} + b^{*2}}$$

La valoración del color y del aspecto exterior puede llevarse a cabo mediante escalas de puntuanción. Las escalas pueden resultar un valioso método para la valoración de las características visuales de un producto mínimamente procesado. Diversos investigadores han empleado este tipo de escalas para evaluar el aspecto exterior y las diferencias entre diversos tratamientos de productos cortados como el melocotón o la nectarina (Gorny et al., 1998, 1999), mezclas de verduras (Amodio et al., 2006) o hojas de menta (Kenigsbuch et al., 2007).

Kader y Cantwell (2004) publicaron trabajos experimentales para la valoración del aspecto exterior mediante escalas de puntuación y papel colorimétrico, sirviendo de gran utilidad a los investigadores y operadores del sector que se ocupan de productos mínimamente procesados.

Las escalas, constituidas para cada producto por cinco fotos acompañadas de un juicio descriptivo sintético de los diversos elementos tomados en consideración, se presentan como un instrumento válido de valoración de la calidad del producto, tanto en investigación como en el ámbito comercial. La valoración del producto se establece con puntuaciones de 1 a 5 donde el valor máximo es 5 y representa el valor óptimo del producto, se atribuye al producto recien cortado de aspecto fresco y sin defectos; 4

representa aspecto bueno y se atribuye al producto que perdiendo algo de la calidad inicial (deshidratación o cambios de color superficiales) mantiene todavía su aspecto fresco; 3 se puntúa al producto mediocre (límite de comercialización) con los requisitos mínimos para que pueda ser aceptado por el consumidor; 2 representa el producto con aspecto malo, el producto mantiene las características para el consumo pero no es aceptado por el consumidor, y 1 es el límite comestible de un producto con aspecto pésimo (con deterioro y cambios significativos del color y de la consistencia).

El empleo y puesta a punto de estas escalas es arbitrario. El objetivo de su uso es que las puntuaciones sean los más objetivas posible con la descripción y las imágenes de la escala. El número de puntos, la puntuación atribuida y las consideraciones en las descripciones, son criterios que se establecen de manera objetiva en el momento de la puesta a punto de la escala (Amodio, et al., 2007).

El color también puede ser medido de manera objetiva y rápida mediante técnicas computerizadas de análisis de imagen, también conocidas como sistemas de visión computerizada. Estos sistemas no sólo ofrecen una metodología para la medida de color de superficies desiguales sino también se utlilizan para medidas de otros atributos del aspecto general (Hutchings, 1999). Las ventajas de la visión computerizada frente a las técnicas tradicionales para la medida del color (colorímetros y espectrofotómetros) han descrito en numerosos estudios (O'Sullivan et al., 2003; Brosnan y Sun, 2004; Chen et al., 2010).

El sistema consiste en la adquisición de una imagen o video digital, una fuente de luz, y un software de procesado de imágenes (Brosnan y Sun, 2002). Partiendo de la imagen RGB, el software puede convertir la imagen original a otros espacios de color tales como L*, a*, b* (León et al., 2006) o HSV (Peri et al., 2005), los cuales son normalmente usados como referencias en investigación con alimentos. El paso más crítico en el procesado de la imagen es el de aislar la región a estudios (que puede ser la imagen entera o sólo una parte) dentro de la imagen, y esto se realiza mediante la segmentación de la imagen (Gunasekaran, 1996). La segmentación de la imagen y las medidas del color pueden llevarse a cabo mediante un algoritmos, tal y como cita la literatura para algunas aplicaciones como la evalucación del color y la incidencia del pardeamiento de hojas de albahaca (Peri et al., 2005), y el color del músculo y el

veteado característico en ternera (Jackman et al., 2009; Chen et al., 2010). No existen aplicaciones actualmente disponibles para alcachofas o patatas cuarta gama, y siendo esto un factor limitante en la investigación sobre tratamientos antipardeamiento en estos productos.

Capítulo 4

Capítulo 4. SELECCIÓN DE VARIDADES DE PATATA Y ALCACHOFA PARA SU UTILIZACIÓN EN LA INDUSTRIA DE LA IV GAMA

4.1. SUITABILITY OF FIVE DIFFERENT POTATO CULTIVARS (*Solanum tuberosum* L.) TO BE PROCESSED AS FRESH-CUT PRODUCTS. POSTHARVEST BIOLOGY AND TECHNOLOGY 53, 138–144 (2009)

Postharvest Biology and Technology 53 (2009) 138–144

Contents lists available at ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Suitability of five different potato cultivars (*Solanum tuberosum L.*) to be processed as fresh-cut products

Ana B. Cabezas-Serrano [a], Maria L. Amodio [b], Rosaria Cornacchia [b], Raffaella Rinaldi [b], Giancarlo Colelli [b,*]

[a] Departamento de Bromatología y Tecnología de los Alimentos, Universidad de Córdoba, Campus Rabanales, 14001 Cordoba, Spain
[b] Dipartimento di Scienze delle Produzioni e dell'Innovazione nei Sistemi Agro-Alimentari Mediterranei - Università degli Studi di Foggia, Via Napoli 25, 71100 Foggia, Italy

ARTICLE INFO

Article history:
Received 12 September 2008
Accepted 24 March 2009

Keywords:
Phenols
Browning
Ascorbic acid
Antioxidant activity
PPO activity
PAL activity

ABSTRACT

Five different potato cultivars ('Agata', 'Agria', 'Almera', Marabel' and 'Vivaldi') were cut and stored at two temperatures (5 and 20 °C) for 9 d in order to investigate their browning potential and their suitability to be processed as fresh-cut product on the basis of their initial quality attributes such as color, water content, polyphenol oxidase (PPO) and phenylalanine ammonia-lyase (PAL) activities, total phenolics, ascorbic acid contents, sugar composition and antioxidant activity (AOX). In addition, color changes and general appearance were monitored during storage. ANOVA results showed that the five cultivars were characterized by different initial color and yellow intensity with b^* decreasing significantly from 'Marabel' (30.6), to 'Agria' (28.0), 'Almera' (21.6), 'Vivaldi' (19.6), and 'Agata' (16.5). Initial composition varied widely among cultivars and accounted for the different post-cutting performances. 'Marabel' and 'Agata' potatoes showed least color changes among the five cultivars, and scored the maximum for appearance when stored at 5 °C, while 'Marabel' received the highest score also when stored at 20 °C. 'Marabel' showed a relatively low phenol content (32.5 mg GE/100 g fw), low PPO activity (10.02 U/g fw), one of the highest antioxidant activities (18.02 mg TE/100 g fw) and the highest soluble sugar content (2.3 g/100 g fw). 'Vivaldi' and 'Agria' cultivars showed an intermediate potential in terms of storability and appearance, while 'Almera' was the less suitable cultivar to be used as fresh-cut, despite its high content in ascorbic acid (34.8 mg/100 g fw) and high antioxidant activity (23.2 mg TE/100 g fw), also showing one of the highest phenol content (46.1 mg GE/100 g fw) and PPO activity (14.7 U/g fw). A principal component analysis on the chemical and physical attributes showed a high correlation between phenol content, PAL and PPO activity, a^* value, and hue angle variation at 5 and 20 °C. Appearance score, and fructose and glucose contents were positively correlated with each other and inversely correlated with hue angle variation. Score, and fructose and glucose contents allowed discrimination between 'Marabel' and the other varieties. 'Marabel' and 'Agata' potatoes were represented by the negative portion of Principal Component 2, while 'Almera', 'Agata', and 'Agria' were located on the positive axis, highly correlated with hue angle variation which was statistically higher for these varieties.

1. Introduction

Due to the consumer demand for high-convenience food, fresh-cut potatoes may represent an interesting product to add to existing fresh-cut products. The quality of a fresh-cut product is generally affected by preharvest and postharvest factors, including processing. Genotype is one of the most important preharvest factors, and the first to be evaluated in order to select cultivars to be processed as fresh-cut products. Since cultivars vary in their genetic make-up, fresh produce varies in attributes such as size, color, flavour, texture, nutrition, pest resistance, processing ability, eating quality and yield (Beverly et al., 1993). The susceptibility to browning may differ from cultivar to cultivar, as observed for apple, potatoes, nectarines, and peaches (Janovitz-Klapp et al., 1989; Mattilia et al., 1993; Gorny et al., 1999). This may be explained by the differences in phenols, antioxidant content, and enzyme activities. Enzymatic browning is the consequence of the reaction between oxidative enzymes, such as polyphenol oxidase and/or phenol peroxidases, and phenols (Degl'Innocenti et al., 2005). When initial events due to degenerative processes or wounding break down cell compartmentalization (Marangoni et al., 1996), polyphenol substrates can be mixed with oxidative enzymes (Degl'Innocenti et al., 2005). In fresh-cut artichokes, phenol content was found to be correlated with browning susceptibility since its initial high content may induce the browning reaction (Brecht et al., 2004), while in fresh-cut lettuce, in which the initial phenol content is very low, browning was correlated with PAL activity, a key enzyme in phenol biosynthesis (Couture et al., 1993). In this case, browning is a result of an active inductive process,

* Corresponding author. Tel.: +39 0881 589105.
E-mail address: g.colelli@unifg.it (G. Colelli).

0925-5214/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.postharvbio.2009.03.009

requiring *de novo* synthesis of PAL and the consequent accumulation of phenolic compounds, rather than a passive oxidation of pre-existing phenols (Saltveit, 2000). For fresh-cut potatoes, Cantos et al. (2002) found a correlation between browning and PAL activity only during the first 4 d after wounding, suggesting that PAL activity is not the rate-limiting step in browning development, and that membrane stability might be a potential major factor controlling the browning rate. In their study, they found a different browning susceptibility of five potato varieties, with 'Agria' showing the best performances with respect to 'Cara', 'Monalisa', 'Spunta', and 'Liseta'. Phenol content was found to vary greatly among different potato cultivars (Tudela et al., 2002a; Thybo et al., 2006; Mattila and Hellström, 2007), as well as total vitamin C (Han et al., 2004), and ascorbic and dehydro-ascorbic acid (Tudela et al., 2002b). Antioxidant activity was positively related to phenol content (Teow et al., 2007) and varied widely among several genotypes of sweet potatoes (Huang et al., 2006; Teow et al., 2007). The presence of antioxidant compounds such as ascorbic acid may also prevent browning reactions (Cocci et al., 2006) and this was also suggested as an explanation for the lower susceptibility of rocket leaves to browning, compared to fresh-cut lettuce (Degl'Innocenti et al., 2007). In a study on the effects of variety, wounding and storage time on the quality of six pre-peeled potato varieties, Thybo et al. (2006) found a strong effect of the cultivar on the sensory attributes and chemical components, pointing out the importance of the cultivar choice and of the quality of the raw material on the final product.

The present study represents a further contribution to the selection of potato varieties to be processed as fresh-cut product. It is designed to better understand the relations between the composition and post-cutting behavior of five potato cultivars, through possible links among antioxidant compounds, phenols, enzymatic activity, sugar composition and appearance.

2. Materials and methods

2.1. Raw material

Potato tubers (*Solanum tuberosum L.*) of five different cultivars available on the Italian market, 'Agata', 'Agria', 'Almera', 'Marabel', and 'Vivaldi', were purchased from a local potato growers association and transported to the Postharvest Laboratory of the University of Foggia.

2.2. Sample processing and storage conditions

Tubers were washed in chlorinated water (100 ppm of free chlorine), in order to reduce surface contamination. Potatoes were then hand-peeled with a sharp knife, and cut into two halves. One half of each tuber was frozen and then used for chemical determinations at harvest, while the other half was cut into 2 cm slices and then into cubes, with a commercial cutting grid. Cubes were immediately immersed in chlorinated water in order to prevent browning. Each replicate was made up of 30 cubes (15 × 2 temperatures of storage) and cutting operations were replicated three times for each cultivar. In the end, cubes were paper-dried, and separated in two lots of 15 cubes, one for each temperature of storage, namely 5 and 20 °C. After cutting, and after 1, 3, 5, 7, and 9 d of storage at 5 and 20 °C, non-destructive evaluations of color and general appearance were performed on each replicate.

2.3. Chemical determinations at harvest

2.3.1. Dry matter

Samples of 5 g of ground potatoes were dried at 65 °C until constant weight.

2.3.2. Vitamin C

Ten grams of fresh tissue were homogenized with 10 mL of MeOH:H_2O (5:95) plus citric acid (21 g/L) with EDTA (0.5 g/L) and NaF (0.168 g/L). The homogenate was filtered through cheesecloth and C18 Bakerbond SPE cartridge (Baker, Deventer, Holland). Ascorbic acid (AA) and dehydro-ascorbic acid (DHAA) contents were determined as described by Zapata and Dufour (1992). The HPLC analysis was carried out after derivatization of DHAA into the fluorophore 3-(1,2-dihydroxyethyl) furol [3,4-b]quinoxaline-1-one (DFQ), with 1,2-phenylenediamine dihydrochloride (OPDA). 20 μL samples were analyzed with an HPLC (Agilent Technologies 1200 Series, Waldbronn, Germany) equipped with a DAD detector and a binary pump. Separations of DFQ and AA were achieved on a Zorbax Eclipse XDB- C18 column (150 mm × 4.6 mm; 5 μm particle size; Agilent Technologies, Santa Clara, CA, USA). The mobile phase was MeOH:H_2O (5:95, v/v) containing 5 mM cetrimide and 50 mM potassium dihydrogen phosphate at pH 4.5. The flow rate was 1 mL/min. The detector wavelengths were 348 nm for DHA and 251 nm for AA. Total ascorbic acid (AA + DHAA) was expressed as mg/100 g of fresh weight (fw).

2.3.3. Sugar composition

For sugar composition, 5 g of frozen tissue were homogenized in 10 mL of water. Extracts were then centrifuged at 12,000 × *g* for 5 min, filtered through C18 Bakerbond SPE cartridge (Baker, Deventer, Holland) and a 0.45 μm filter and injected into the HPLC system equipped with Refractive Index Detector (RID). Individual peaks were separated on an Alltima Amino (250 mm × 4.6 mm; 5 μm particle size; Alltech, Deerfield, IL, USA) quantified by comparison to standard solutions of glucose, sucrose and fructose and expressed as g/100 g of fresh weight (fw). The flow rate was 1 mL/min.

2.3.4. Total phenol content and antioxidant activity

The same extraction was conducted for both total phenols and antioxidant activity. Five grams of potato tissues were homogenized in 2 mM sodium fluoride methanol:water solution (80:20) for 1 min, and then centrifuged at 5 °C and 12,000 × *g* for 5 min. Total phenols were determined according to the method of Singleton and Rossi (1965). Each extract (100 μL) was mixed with 1.58 mL of water, 100 μL of Folin–Ciocalteau's reagent, and 300 μL of sodium carbonate solution (200 g/L). After 2 h, the absorbance was read at 575 nm against a blank in a spectrophotometer (Shimadzu UV-1700l, Jiangsu, China). The total phenol content was calculated on the basis of the calibration curves of gallic acid, and was expressed as mg of gallic acid equivalents per 100 g of fresh weight (mg GAE/100 g fw). Antioxidant assay was performed following the procedure described by Brand-Williams et al. (1995), with minor modifications. The diluted sample (100 μL) was pipetted into 0.9 mL of DPPH solution to initiate the reaction. The absorbance was read after 15 min at 515 nm. Trolox was used as a standard and the antioxidant activity was reported in mg of Trolox equivalents per 100 g of fresh weight (mg TE/100 g fw).

2.3.5. PAL activity

PAL activity was measured as previously described by Martínez-Téllez and Lafuente (1997), with slight modifications. Five grams of frozen tissues were homogenized in 20 mL of cold acetone for 1 min. The residue was washed with cold ethanol and filtered. The powder was then dried at room temperature. PAL was extracted from 200 mg of acetone powder with 10 mL of sodium borate buffer (pH 8.8), containing 0.02% of ascorbate. PAL activity was measured by determining the absorbance of cinnamic acid at 290 nm over a period of 1 h at 37 °C. The reaction mixture contained 1 mL of extract, 2 mL of water, and 1 mL of 60 μM L-phenylalanine. The results were expressed as μmol/L of cinnamic acid equivalents per gram of fresh weight (μ mol CE/L/g fw).

2.3.6. PPO activity

For PPO activity, 5 g of frozen tissue powder were homogenized in 30 mL of 0.1 M phosphate buffer, pH 6, together with 1 g of polyvinylpyrrolidone (PVP), and centrifuged at 12,000 × *g* for 15 min. The supernatant was used for PPO activity measured by determining the absorbance increase at 410 nm over a period of 2 min at 25 °C. The reaction mixture contained 1.5 mL of extract, 1 mL of phosphate buffer, and 0.5 mL of 100 mM 4-methylcatechol. The results were expressed as units of enzymatic activities. One unit of enzyme activity was defined as the amount of the enzyme, which caused a 0.01 change in absorbance in the first 15 s, that were within the first linear region of each curve (Kahn, 1977).

2.4. Cube evaluations at harvest and during storage

2.4.1. Overall appearance evaluation

Cubes were evaluated subjectively on a 5 to 1 scale, where 5 = excellent, no defects, 4 = very good, minor defects, 3 = fair, moderate defects, 2 = poor, major defects, 1 = inedible. A score of 3 was considered as the limit of marketability and a score of 2 as the limit of edibility (Amodio et al., 2007).

2.4.2. Color evaluations

Color was measured on each potato cube with a MINOLTA tristimulus colorimeter set with illuminant C ($\Delta E/^{\circ}C = 0.05$), measuring $L^*a^*b^*$ parameters in the CIE scale and calculating hue angle = arctg b^*/a^* and chromaticity = $\sqrt{a*^2 + b*^2}$. In addition, in order to compare samples with different initial color, ΔL^*, Δa^*, Δb^* were calculated as % of the initial value, and ΔE was also calculated as $\sqrt{(L* - L_0*)^2 + (a* - a_0*)^2 + (b* - b_0*)^2}$.

2.5. Statistical analysis

The analysis of variance was performed on data of initial determinations in order to detect differences among cultivars. For each storage temperature, the analysis of variance (two-way ANOVA) was performed using a split-plot design considering the variety as the first factor and the time of storage as the second factor. The most conservative degrees of freedom were used to determine the effect of time, and variety × time interaction. At each storage evaluation, the effect of the cultivar was assessed with a one-way ANOVA. Means were separated using Tukey's test. Moreover, a multivariate Principal Component Analysis (PCA) was performed on the initial attributes, on delta hue angle, and on the mean score evaluation at 5 and 20 °C, to establish a preliminary relationship between cultivars and the parameters studied in this work.

3. Results

3.1. Initial color and chemical composition

Color measurements just after cutting are reported in Table 1. The degree of yellowness in potato pulps, described by b^* values, increased from 'Agata', to 'Vivaldi', 'Almera', 'Agria', and to 'Marabel', ranging from 16.7 to 30.5. 'Marabel' was also characterized by the highest L^* value (70.9) and chroma (30.1), and the lowest a^* value (−5.1), which provided evidence of its lighter yellow color. On the other hand, 'Agata' had the lowest L^* value (65.0) and together with 'Vivaldi' showed hue angle values higher than 'Marabel', 'Agria', and 'Almera'. These values were located in the second quarter of the CIE $L^*a^*b^*$ color scale, with the highest values verging on the green side, and the lowest ones on the yellow side.

Table 1
Initial color evaluations of five potato cultivars. Within the same row, values followed by the same letter are not significantly different, $P \leq 0.05$.

Color evaluations	AGATA	AGRIA	ALMERA	MARABEL	VIVALDI
L^* value	65.0 c	71.3 a	67.2 b	70.9 a	70.6 a
a^* value	−3.7 a	−4.3 b	−3.7 a	−5.1 c	−4.0 ab
b^* value	16.7 e	28.0 b	21.6 c	30.5 a	19.6 d
Hue angle	1.79 a	1.72 b	1.74 b	1.74 b	1.77 a
Chroma	17.1 e	28.3 b	21.9 c	31.0 a	20.0 d

Chemical parameters showed great variability within varieties, as reported in Table 2. Water content ranged from 77.7% in 'Agria' to 83.5% in 'Agata', while total ascorbic acid (AA + DHAA) ranged from 16.1 in 'Vivaldi' to 34.8 mg/100 g in 'Almera'. The latter also showed the highest phenol content (46.1 mg GE/100 g fw), PAL activity (0.013 μmol CE/L/g fw), and antioxidant activity (23.2 mg TE/100 g fw), which is affected by the presence of both phenols and ascorbic acid, and which was about twice that of 'Vivaldi'. 'Marabel' presented the lowest phenol content (about 60% of 'Almera'), the highest total soluble sugar content (2.3 g/100 g fw), and the lowest PPO activity (10 U/g fw). In general, no relations between initial color and chemical composition could be observed. While some cultivars showed low enzymatic activity and low oxidation substrate content, other cultivars with a high antioxidant activity also displayed high phenol content.

3.2. Effect of cultivar on post-cutting browning of potato cubes during storage

The cultivar affected color changes and appearance score at both temperatures of storage. Table 3 reports the effect of cultivar, time of storage, and of their interaction on these non-destructive parameters, during storage at 5 and 20 °C. At 5 °C, the cultivar affected the appearance score, the color changes related to a^* and b^*, ΔE, Δchroma, while time affected all the parameters, except ΔL^* and ΔE. The *cultivar* × *time* interaction was not significant, showing that behavior patterns of each cultivar were consistent over time. At room temperature, cultivar and time affected all measured parameters, while their interaction was significant only for Δb^* and Δchroma.

The main effect of the cultivar on quality attributes of potato cubes stored for 9 d at 5 and 20 °C is reported in Table 4, as mean val-

Table 2
Initial chemical composition of 5 potato cultivars. Within the same row, values followed by the same letter are not significantly different, $P \leq 0.05$.

Chemical composition	AGATA	AGRIA	ALMERA	MARABEL	VIVALDI
Water content (%)	83.5 a	77.7 d	80.9 b	80.8 bc	78.6 cd
Ascorbic acid (mg/100 g fw)	21.5 cd	31.1 ab	34.8 a	25.3 bc	16.1 d
Total phenolics (mg GE/100 g fw)	38.6 ab	37.2 ab	46.1 a	32.7 b	35.4 ab
Antioxidant activity (mg TE/100 g fw)	12.3 bc	18.8 ab	23.2 a	18.0 ab	11.1 c
PAL activity (μmol CE/L/g fw)	0.011 ab	0.008 b	0.013 a	0.009 ab	0.011 ab
PPO activity (U/g fw)	14.7 a	13.0 ab	12.2 abc	10.0 c	11.5 bc
Fructose (g/100 g fw)	0.7 b	0.6 b	0.7 b	0.9 a	0.7 b
Glucose (g/100 g fw)	0.8 ab	0.6 b	0.8 ab	1.0 a	0.8 ab
Sucrose (g/100 g fw) nd	–	0.2 b	0.2 b	0.4 a	0.2 b
Total soluble sugars (g/100 g fw)	1.5 b	1.4 c	1.7 ab	2.3 a	1.7 ab

nd = non-detected.

Table 3
Effect of cultivar, time of storage, and of cultivar × time interaction on appearance score and color changes of potato cubes stored at 5 and 20 °C.

	Score	ΔL (%)	Δa (%)	Δb (%)	ΔE	ΔHue (%)	ΔChroma (%)
5 °C							
Cultivar	*	ns	*	**	**	ns	***
Time	****	ns	****	****	ns	****	****
Cultivar X time	ns	ns	ns	ns	ns	ns	Ns
20 °C							
Cultivar	****	*	****	****	***	****	****
Time	**	****	****	****	****	****	**
Cultivar X time	ns	ns	ns	**	ns	ns	**

$^{*}P \leq 0.05$; $^{**}P \leq 0.01$; $^{***}P \leq 0.001$; $^{****}P \leq 0.0001$.

ues throughout the storage period. Overall appearance score at 5 °C remained above the limit of marketability for all cultivars ranging from 3.3 for 'Almera', to 3.9 for 'Marabel', which was significantly higher than 'Agria', 'Vivaldi' and 'Almera'. Score value for 'Agata' (3.8) was significantly different only from 'Almera'.

Color changes over storage time showed great variability within cultivars. In general, samples with the lowest mean Δvalues were more similar to the initial value, hence more fresh-like. At 5 °C, while ΔL^* was not affected by the cultivar, variations in a^* and b^* values were highly considerable. 'Agata' and 'Marabel' showed only 24% variation for a^* values, 'Vivaldi' 42%, while 'Agria' and 'Almera' exhibited more than 50% of variation of a^* values, indicating the highest increase in the red component, related to a high browning incidence. Variation in b^* values ranged from 10.0% in 'Agria' to negative values of −13.2% in 'Vivaldi', where negative values indicated an increase in this parameter over time, with 'Marabel' showing only a −0.5% variation, very similar to the initial value. The mean ΔE values, which summarize the overall color variations during storage at 5 °C, ranged from 2 and 2.6 for 'Marabel' and 'Agata', to about 4 for 'Almera' and 'Vivaldi', and up to 5 for 'Agria'. In the CIE $L^*a^*b^*$ color scale, ΔE differences from 2 to 3 are considered fairly perceptible by the human eye, while differences from 4 to 6 are considered perceptible (CIE, 2004).

'Marabel' and 'Agata', that scored the highest for appearance, showed the lowest color variation. On the other hand, 'Agria' and 'Almera' which received the lowest score for appearance, also showed the highest variation in color (as for Δa^*, Δb^* and ΔE). 'Vivaldi' showed the lowest variations of b^* and chroma, together with 'Agata', and, in general, an intermediate behavior among cultivars.

During storage at room temperature, effects were amplified with more evident changes (Table 4). For appearance, again 'Marabel' was the cultivar with the highest score, 'Agata' had the second highest value (both equal to or higher than 3). No differences were detected between 'Agria' (2.8) and 'Vivaldi' (2.9), while 'Almera' received the lowest score (2.6). In this case, it can be observed that only 2 out of 5 cultivars maintained a mean score value above the limit of marketability, since high temperature speeded up degradation processes in potato cubes. Accordingly, also color change rates varied to a greater extent (Table 4). For instance, a^* values varied from 78.6% in 'Agata' (versus 24% of variation at 5 °C) to 121.6% in 'Agria' (versus 54.7% at 5 °C), hue varied from 9.8% in 'Marabel' (versus 2.3 at 5 °C) to 11.6% in 'Agria' (versus 4.3% at 5 °C).

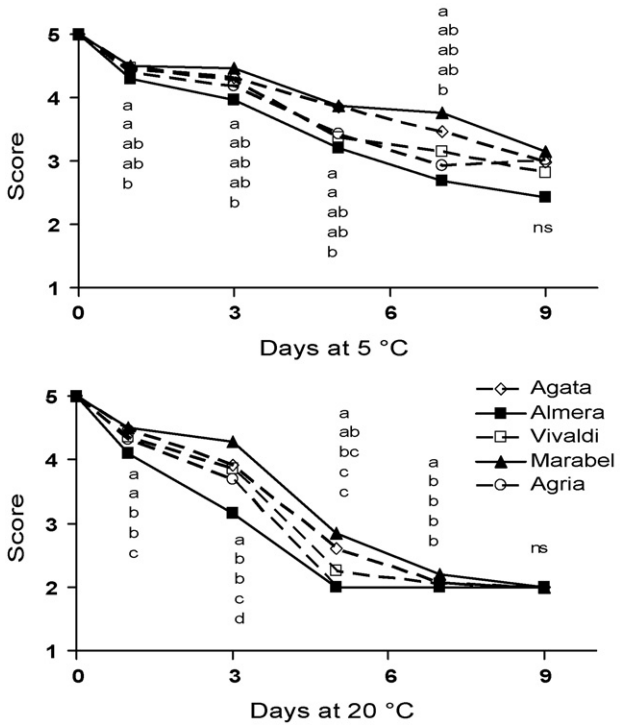


Fig. 1. Effect of cultivar on score appearance of potato cubes stored at 5 °C and at 20 °C. Within the same storage time, values with the same letter are not significantly different, $P \leq 0.05$.

Score evaluation throughout storage is reported in Fig. 1. At 5 °C, 'Almera' could be identified as the cultivar with the worst appearance, with a score value consistently lower than 'Marabel', and at day 1 and day 5 also lower than 'Agata'. At room temperature, the five cultivars had a different behavior during the first 5 d of storage, with differences becoming smaller over time; at day 7 only 'Marabel' scored significantly better than the others, while no differences were detected at the end of storage.

Table 4
Effect of cultivar on appearance score and color changes of potato cubes stored at 5 and 20 °C. Within the same row, values followed by the same letter are not significantly different, $P \leq 0.05$.

Temperature of storage	Quality parameters	AGATA	AGRIA	ALMERA	MARABEL	VIVALDI
5 °C	Score	3.8 ab	3.6 bc	3.3 c	3.9 a	3.6 b
	ΔL^* (%)	−0.5 ns	3.2 ns	2.8 ns	−0.5 ns	2.3 ns
	Δa^* (%)	24.1 c	54.7 a	50.9 a	24.5 c	42.14 b
	Δb^* (%)	−9.8 d	10.0 a	6.0 b	−0.5 c	−13.2 d
	ΔE	2.7 c	5.0 a	4.1 ab	2.2 c	3.9 b
	ΔHue (%)	3.5 b	4.3 ab	4.5 a	2.3 c	5.2 a
	ΔChroma (%)	−8.47 d	10.68 a	6.90 b	0.05 c	−11.68 d
20 °C	Score	3.0 b	2.8 c	2.6 d	3.2 a	2.9 c
	ΔL^* (%)	2.9 b	5.5 a	4.6 ab	4.6 ab	5.8 a
	Δa^* (%)	78.6 b	121.6 a	113.8 ab	99.9 ab	105.5 ab
	Δb^* (%)	−27.0 c	11.6 a	1.7 b	5.5 ab	−22.6 c
	ΔE	6.0 b	7.7 a	6.0 b	6.5 b	7.6 a
	ΔHue (%)	9.9 b	11.6 a	11.2 a	9.8 b	11.7 a
	ΔChroma (%)	−24.6 e	12.2 a	2.6 c	6.3 b	−20.6 d

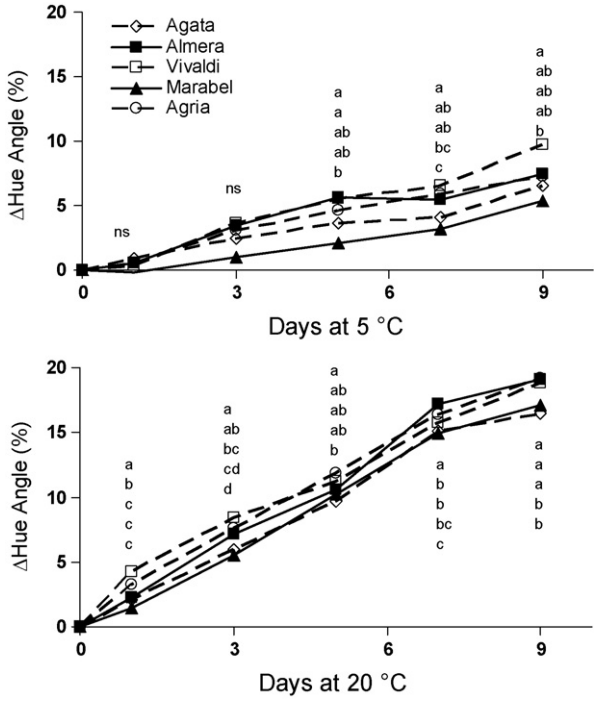


Fig. 2. Effect of cultivar on color change (Δhue angle) of potato cubes stored at 5 °C and at 20 °C. Within the same storage time, values with the same letter are not significantly different, $P \leq 0.05$.

Hue angle changes during storage are reported in Fig. 2. Differences in Δhue angle at 5 °C were observed starting from day 5 with 'Almera' and 'Vivaldi' showing higher hue variation than 'Marabel'. Later during the storage time, 'Vivaldi' showed a higher percentage of hue variation than 'Marabel' and 'Agata' after 7 d, and only higher than 'Marabel' after 9 d. Hue angle variation patterns of potato cubes stored at 20 °C consistently changed throughout storage, with 'Vivaldi', 'Agria' and 'Almera' significantly higher than 'Marabel' and 'Agata'.

3.3. Principal component analysis on chemical attributes and color changes

Different performances among potato cultivars and their potential to be processed as a fresh-cut products were confirmed by PCA (Fig. 3). Two main principal components described potato attributes and color changes during storage at 5 and 20 °C (67.7% of total variance). Principal component 1 (PC1) accounted for 39.8% and principal component 2 (PC2) for 27.9%. PC1 describes the differences in terms of phenol content, PAL and PPO activities, a^* value, and Δhue angle, versus antioxidant activity, score, sugar content, vitamin C, L^* and b^* values. PC2 relates to color attributes and changes during time, PAL activity, antioxidant activity, sucrose content and vitamin C, versus phenol content and PPO activity, water content, score evaluation at 5 and 20 °C, and fructose and glucose contents. In the PCA bi-plot, three groups of cultivars could be observed: 'Marabel', 'Agata', and a third group represented by 'Almera', 'Agria', and 'Vivaldi', confirming in a general way what was observed by analyzing the color changes throughout the experiment. 'Marabel' was represented by fructose and glucose contents, and by appearance score, whose values were statistically higher than in other varieties (Tables 1 and 4). 'Agata' was better represented by water content, total phenol content and PPO activity; being in the negative portion of PC2, it could be discriminated together with 'Marabel' from the other cultivars by the lower hue angle variations. 'Agria', 'Almera', and 'Vivaldi' were correlated with

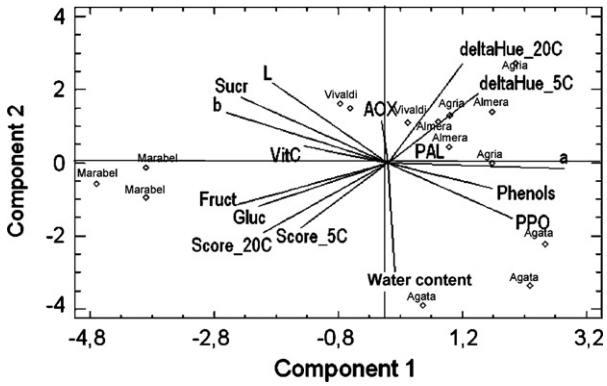


Fig. 3. Principal component analysis bi-plot (Component 1 versus Component 2) of chemical composition (sucrose = sucr; fruct = fructose; vitamin C = vitC; antioxidant activity = AOX; PAL activity = PAL; PPO activity = PPO; phenols), initial color ($L^* = L$; $a^* = a$; $b^* = b$), color changes (Δhue angle at 5 °C = deltahue_5C; Δhue angle at 20 °C = deltahue_20C), and mean appearance score (score at 5 °C = score_5C; score at 20 °C = score_20C) of five potato cultivars.

antioxidant activity, PAL activity, and hue angle changes over time. Hue angle variation at 20 °C, which had the greatest influence on PC2, was, statistically higher for 'Almera', 'Agria' and 'Vivaldi' than for 'Agata' and 'Marabel' (Table 4). As for quality attributes included in the PCA, four groups positively correlated with each other, were identified on the four quarters of the PCA plot. That was the case for PPO and PAL activities, total phenol content, water content, and a^* value in the right-bottom quarter; Δhue angle at 5 °C and at 20 °C in the right-top quarter; antioxidant activity, L^* and b^* values, vitamin C and sucrose contents in the left-top quarter; finally, fructose and glucose contents, and appearance scores at 5 °C and at 20 °C in the left-bottom quarter. It is interesting to observe that a^* value, phenols and PPO activity negatively correlated with L^* value, antioxidant activity and vitamin C, while hue angle variations at both temperatures negatively correlated with score, glucose and fructose content.

4. Discussion

Several differences in terms of initial chemical attributes and post-cutting changes were found among the 5 potato cultivars used in this experiment (Tables 1, 2 and 4), confirming the general finding of several authors on different browning susceptibility of distinct genotypes for apples, potatoes, nectarines, and peaches (Janovitz-Klapp et al., 1989; Mattilia et al., 1993; Gorny et al., 1999). Different performances may be explained with the differences in phenols and total antioxidant contents, and in the enzyme activities. Phenol content was found to vary among potato cultivars (Thybo et al., 2006; Mattila and Hellström, 2007), as well as, ascorbic and dehydro-ascorbic acids (Tudela et al., 2002b). In this work, 'Marabel' and 'Agata' were the two cultivars that showed the longest shelf-life at 5 °C, with 'Marabel' showing the best appearance even when stored for 7 d at 20 °C. These results can be explained by the low phenol content and PPO activity, and by the relatively high antioxidant activity of 'Marabel' potatoes. 'Agata' also showed good performances, despite its high phenol content and PPO activity. Most probably, a high membrane stability, as suggested by Cantos et al. (2002), may explain the good performance of this variety, delaying the contact between PPO enzyme and substrates. The type of phenols and their affinity to the PPO enzyme can also explain the low browning susceptibility of fresh-cut 'Agata' potatoes. Not all the phenols have the same affinity with PPO enzymes. Some authors, in fact, found a positive correlation between tyrosine and chlorogenic acid with PPO activity (Friedman, 1997; Thybo et al., 2006), while Thybo et al. (2006) found a negative correlation

between caffeic acid and enzymatic discoloration in pre-peeled potatoes. On the other hand, 'Almera' had the worst post-cutting performance, probably related to its high PAL activity content and phenol content. Enzymatic browning is the consequence of the reaction between oxidative enzymes, such as polyphenol oxidase and/or phenol peroxidases, and phenols (Degl'Innocenti et al., 2005), that takes place after the breakdown of cell compartmentalization (Marangoni et al., 1996; Degl'Innocenti et al., 2005). Phenol content is found to be correlated with browning susceptibility in plant species rich in these constituents, such as artichokes (Brecht et al., 2004), while in species with a low initial phenol content, such as lettuce, browning was correlated with PAL activity, due to the consequent accumulation of phenolic compounds (Saltveit, 2000). According to Cantos et al. (2002), potato phenol content does not limit the browning rate, because of its relatively high content; they partially explain the browning susceptibility of five potato cultivars with the extent of PAL activity, only for the first 4 d of storage.

PCA results were in accordance with ANOVA results, and allowed grouping of the different cultivars based on the main attributes. 'Marabel' could be separated from 'Almera', 'Agria' and 'Vivaldi' mainly for score, glucose and fructose contents, and for minor color changes. The high sugar content of this variety may be an additional factor playing a role in preventing potato browning; a slight inhibitory effect due to fructose and glucose solutions was observed on PPO apple extracts (Billaud et al., 2003). The high phenol content and high PAL activity may explain the susceptibility of Vivaldi', 'Almera' and 'Agria' to browning.

PCA also showed good correlations among phenol content, PPO and PAL activities, that negatively correlated with vitamin C, antioxidant activity, and initial L^* and b^* values. Other authors did not find any correlation between the total phenol content and antioxidant activity in 92 plant extracts (Kahkonen et al., 1999). On the other hand, for many authors antioxidant activity in fruit and vegetables was mainly attributed to phenol content, as for small fruit (Kalt et al., 1999), sweet potatoes (Teow et al., 2007), and apples (Cocci et al., 2006), in this case together with ascorbic acid. In the present study, antioxidant activity correlated more with ascorbic acid content than with total phenols (Fig. 3), the latter being well correlated with PPO. This can be explained by the fact that antioxidant capacity is mainly provided by ascorbic acid, while phenolic contribution to oxidative reaction is more decisive than its antioxidant role. In fact, antioxidant activity and vitamin C correlated with initial L^* and b^* values and with appearance score, while total phenol content correlated with the increase in hue angle variation. This matches the findings of several authors reporting a high correlation of browning score and hue angle, slightly higher than that with a^* value (Heimdal et al., 1995; Peiser et al., 1998) on cut iceberg lettuce. The role of ascorbic acid in preventing browning has been confirmed by several experiments in lettuce (Heimdal et al., 1995; Degl'Innocenti et al., 2007), and some other vegetables (Reyes et al., 2007). The high content of ascorbic acid and the high antioxidant activity in 'Almera' did not prevent browning, most probably because of the very high phenol content, and the high PPO and PAL activity.

Cantos et al. (2002) reported that 'Agria' was less susceptible to browning in a list of 5 cultivars; in the present study 'Agria' performance was comparable to that of 'Almera' and 'Vivaldi', and all of them proved to be less suitable for fresh-cut processing than 'Marabel' and 'Agata'. These results confirmed the extreme differences existing among potato cultivars in terms of post-cutting performance, and the need for eventually testing new varieties.

Beside browning potential, sensory attributes also deserve consideration. Thybo et al. (2006) found a strong effect of the cultivar on the sensory characteristics of pre-peeled potatoes, reporting a high off-flavour intensity, and moistness in 'Marabel'. In the present study, although a systematic analysis of the sensory attributes was not carried out, preliminary spare test trials performed upon cooking did not present any sort of organoleptic problem, neither in terms of taste, nor in terms of texture. Since many factors may affect these attributes, including preharvest conditions and postharvest handling (Mattheis and Fellman, 1999), further investigation may be needed for these aspects.

5. Conclusion

Among the potato cultivars used in this experiment in order to asses their suitability to be processed as a fresh-cut product, 'Marabel' showed less browning incidence and color changes and, together with 'Agata', received the highest appearance score during storage at 5 °C. 'Marabel' was characterized by a low phenol content and PPO activity, and high antioxidant activity and sugar content. 'Vivaldi' and 'Agria' varieties showed intermediate potential in terms of storability and appearance, while 'Almera' was the less suitable to be used as fresh-cut, despite its high content in ascorbic acid and high antioxidant activity, most probably because of its high phenol content and PAL activity.

The use of PCA analysis allowed for an explanation of differences in browning susceptibility among potato varieties, taking into account chemical composition, initial color, and post-cutting performances. Initial composition, in terms of phenol content, vitamin C, sugar content, antioxidant and enzymatic activity, partially explained potato suitability to be processed as fresh-cut produce, while the impact of different phenol composition and membrane stability need further investigations. Results of this work confirmed the extreme differences existing among potato varieties in terms of post-cutting performances, and the need to extend the screening to other varieties, in order to have more raw material available for processing according to the season availability. In addition, when the same performances are obtained, the choice may be directed to those varieties with higher nutritional value.

References

Amodio, M.L., Cabezas-Serrano, A.B., Rinaldi, R., Colelli, G., 2007. Implementation of rating scales for visual quality evaluation of various vegetable crops. In: Kader, A.A., Cantwell, M. (Eds.), Produce Quality Rating Scales and Color Charts, Postharvest Horticulture Series NO. 23. University of California, Davis, CA-USA.

Billaud, C., Roux, E., Brun-Merimee, S., Maraschin, C., Nicolas, J., 2003. Inhibitory effect of unheated and heated -glucose -fructose and -cysteine solutions and Maillard reaction product model systems on polyphenoloxidase from apple. I. Enzymatic browning and enzyme activity inhibition using spectrophotometric and polarographic methods. Food Chem. 81, 35–50.

Brand-Williams, W., Cuvelier, M.E., Berset, C., 1995. Use of a free radical method to evaluate antioxidant activity. Lebensm. Wiss. Technol. 28, 25–30.

Beverly, R.B., Latimer, J.G., Smittle, D.A., 1993. Preharvest physiological and cultural effects on postharvest quality. In: Shewfelt, R.L., Prussia, S.E. (Eds.), Postharvest Handling: A Systems Approach. Academic Press, New York, pp. 73–98.

Brecht, J.K., Saltveit, M.E., Talcott, S.T., Schneider, K.R., Felkey, K., Bartz, J.A., 2004. Fresh-cut vegetables and fruits. Hortic. Rev. 30, 185–250.

Cantos, E., Tudela, J.A., Gil, M.I., Espín, J.C., 2002. Phenolic compounds and related enzymes are not rate-limiting in browning development of fresh-cut potatoes. J. Agric. Food Chem. 50, 3015–3023.

CIE, 2004. Colorimetry, CIE Pb. 15:2004, Central Bureau of the CIE, Vienna, pp. 20–21.

Cocci, E., Rocculi, E., Romani, S., Dalla Rosa, M., 2006. Changes in nutritional properties of minimally processed apples during storage. Postharvest Biol. Technol. 39, 265–271.

Couture, R., Cantwell, M.I., Ke, D., Saltveit, M.E., 1993. Physiological attributes related to quality attributes and storage life of minimally processed lettuce. HortScience 58, 609–610.

Degl'Innocenti, E., Guidi, L., Paradossi, A., Tognoni, F., 2005. Biochemical study of leaf browning in minimally processed leaves of lettuce (*Lactuca sativa* L. var. Acephala). J. Agric. Food Chem. 52, 9980–9984.

Degl'Innocenti, E., Pardossi, A., Tognoni, F., Guidi, L., 2007. Physiological basis of sensitivity to enzymatic browning in 'lettuce', 'escarole' and 'rocket salad' when stored as fresh-cut products. Food Chem. 104, 209–215.

Friedman, M., 1997. Chemistry, biochemistry and dietary role of potato polyphenols. A review. J. Agric. Food Chem. 45, 1523–1540.

Gorny, J.R., Hess-Pierce, B., Kader, A.A., 1999. Quality changes in fresh-cut peach and nectarine slices as effected by cultivar, storage atmosphere and chemical treatments. J. Food Sci. 64, 429–432.

Han, J.S., Kozukue, N., Young, K.S., Lee, K.R., Friedman, M., 2004. Distribution of ascorbic acid in potato tubers and in home-processed and commercial potato foods. J. Agric. Food Chem. 52, 6516–6521.
Heimdal, H., Kuhn, B.F., Poll, L., Larsen, L.M., 1995. Biochemical changes and sensory quality of shredded and MA-package iceberg lettuce. J. Food Sci. 60, 1265–1268.
Huang, Y.C., Chang, Y.H., Shao, Y.Y., 2006. Effects of genotype and treatment on the antioxidant activity of sweet potato in Taiwan. Food Chem. 98, 529–538.
Janovitz-Klapp, A., Richard, F., Nicolas, J., 1989. Polyphenol oxidase from apple. Partial purification and some properties. Phytochemistry 28, 2903–2907.
Kahkonen, M.P., Hopia, A.I., Vuorela, H.J., Raucha, J.P., Pihlaja, K., Kujala, T.S., Heinonen, M., 1999. Antioxidant activity of plant extracts containing phenolic compounds. J. Agric. Food Chem. 47, 3954–3962.
Kalt, W., Forney, C.F., Martin, A., Prior, R., 1999. Antioxidant capacity, vitamin C, phenolics and anthocyanins after fresh storage of small fruits. J. Agric. Food Chem. 47, 4638–4644.
Kahn, V., 1977. Some biochemical properties of phenol oxidase from two avocado varieties differing in their browning rates. J. Food Sci. 42, 38–43.
Marangoni, A.G., Palma, T., Stanley, D.W., 1996. Membrane effects in postharvest physiology. Postharvest Biol. Technol. 7, 193–217.
Martínez-Téllez, M.A., Lafuente, M.T., 1997. Effect of high temperature conditioning on ethylene, phenylalanine ammonia-lyase, peroxidase and polyphenol oxidase activities in flavedo of chilled 'Fortune' mandarin fruit. J. Plant Physiol. 150, 674–678.
Mattilia, M., Ahvenainen, R., Hurme, E., 1993. Prevention of browning of pre-peeled potato. In: De Baerdemaker, J. et al. (Eds.), COST 94, Proc. Workshop "System and operation for post-harvest quality", Leuven, Belgium.
Mattila, P., Hellström, J., 2007. Phenolic acids in potatoes, vegetables, and some of their products. J. Food Comp. Anal. 20, 152–160.
Mattheis, J.P., Fellman, J.K., 1999. Preharvest factors influencing flavour of fresh fruit and vegetables. Postharvest Biol. Technol. 15, 227–232.
Peiser, G., López-Gálvez, G., Cantwell, M., Saltveit, M.E., 1998. Phenylalanine ammonia lyase inhibitors control browning of cut lettuce. Postharvest Biol. Technol. 14, 171–177.
Reyes, L.F., Villareal, J.E., Cisneros-Zevallos, L., 2007. The increase in antioxidant capacity after wounding depends on the type of fruit or vegetable tissues. Food Chem. 101, 1254–1262.
Saltveit, M.E., 2000. Wound induced changes in phenolic metabolism and tissue browning are altered by heat shock. Postharvest Biol. Technol. 21, 61–69.
Singleton, V.L., Rossi, J.A., 1965. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. Am. J. Enol. Vitic. 16, 144–158.
Teow, C.C., Truong, V.D., McFeeters, R.F., Thompson, R.L., Pecota, K.V., Yencho, G.C., 2007. Antioxidant activities, phenolic and b-carotene contents of sweet potato genotypes with varying flesh colours. Food Chem. 103, 829–838.
Thybo, A.K., Christiansen, J., Kaack, K., Petersen, M.A., 2006. Effect of cultivars, wound healing and storage on sensory quality and chemical components in pre-peeled potatoes. Lebensm. Wiss. Technol. 39, 166–176.
Tudela, J.A., Cantos, E., Espín, J.C., Tomás-Barberán, F.A., Gil, M.I., 2002a. Induction of antioxidant flavonol biosynsthesis in fresh-cut potatoes. Effect of domestic cooking. J. Agric. Food Chem. 50, 5925–5931.
Tudela, J.A., Espín, J.C., Gil, M.I., 2002b. Vitamin C retention in fresh-cut potatoes. Postharvest Biol. Technol. 26, 75–84.
Zapata, S., Dufour, J.F., 1992. Ascorbic, dehydroascorbic and isoascorbic acid simultaneous determinations by reverse phase ion interaction HPLC. J. Food Sci. 57, 506–511.

4.2. SUITABILITY OF 4 POTATO CULTIVARS (*Solanum tuberosum* L.) TO BE PROCESSED AS FRESH-CUT PRODUCT. EARLY CULTIVARS. AMERICAN JOURNAL OF POTATO RESEACH 88, 403-412 (2011)

Am. J. Pot Res (2011) 88:403–412
DOI 10.1007/s12230-011-9206-3

Suitability of 4 Potato Cultivars (*Solanum tuberosum L.*) to be Processed as Fresh-Cut Product. Early Cultivars

Rosaria Cornacchia · Ana Belén Cabezas-Serrano · Maria Luisa Amodio · Giancarlo Colelli

Published online: 9 September 2011

Abstract The study of the suitability of potato cultivars to be processed as fresh-cut is the first step to obtain a fresh-cut product of high quality. In this study, 4 different early potato cultivars ('Ariana', 'Liseta', 'Safrane' and 'Spunta') were cut and stored for 8 days at 5°C and for 6 days at 20°C with the aim to investigate their browning potential and their post-cutting performance on the basis of their initial quality attributes such as color, polyphenol oxidase (PPO) activity, total phenolics, ascorbic acid contents, sugar composition and antioxidant activity (AOX). In addition, color changes and general appearance were monitored during storage, and a study of the correlations among monitored parameters was carried out. Results showed that 'Safrane' had the least color changes and browning incidence. At 5°C, 'Safrane' showed only about 1% variation in L*, statistically lower than 'Spunta' (3.6%) and 'Ariana' (5.1%), and presented the lowest variation in a* value (about 50% vs. 70% for all other cultivars). At 20°C, 'Safrane' and 'Liseta' showed a lower decrease in L* (5.6 and 6.2%, respectively) and ΔE values, (6.0 and 6.1%, respectively), but 'Spunta' and 'Ariana' were the cultivars with the highest decrease in these parameters. 'Safrane' also received the highest appearance score during the first days of storage at both storage temperatures, and had a high ascorbic acid content (31.2 mg/100 g fw) and antioxidant activity (26.6 mg TE/100 g fw). 'Liseta' and 'Ariana' showed intermediate potential in terms of storability and appearance, while 'Spunta' was the least suitable to be used as fresh-cut. Results of this work contributed to increased knowledge on the suitability of potato cultivars to be processed as fresh cut produce, to allow the fresh-cut industry to be supplied with raw material suitable for processing throughout the year, according to seasonal availability.

R. Cornacchia · A. B. Cabezas-Serrano · M. L. Amodio · G. Colelli (✉)
Dipartimento di Scienze delle Produzioni e dell'Innovazione nei Sistemi Agro-alimentari Mediterranei,
Università degli Studi di Foggia,
Via Napoli 25,
71100 Foggia, Italy
e-mail: g.colelli@unifg.it

Resumen El estudio de la factibilidad de las variedades de papa para ser procesadas como corte fresco es el primer paso para obtener un producto recién cortado de alta calidad. En este estudio se cortaron y almacenaron por 8 días a 5°C y por 6 días a 20°C, cuatro variedades tempranas diferentes ("Ariana", "Liseta", "Safrane" y "Spunta"), con el objetivo de investigar su potencial pardeamiento y su comportamiento post-corte con base a sus atributos de calidad inicial, tales como el color, la actividad de la polifenol-oxidasa (PPO), fenoles totales, contenido de ácido ascórbico, composición de azúcar y actividad antioxidante(AOX). Además, se estuvieron observando durante el almacenamiento los cambios de color y la apariencia general, y se efectuó un estudio de las correlaciones entre los parámetros monitoreados. Los resultados demostraron que "Safrane" tuvo los menores cambios de color e incidencia de pardeamiento. A 5°C, "Safrane" mostró solamente cerca de 1% de variación en L*, estadísticamente más bajo que "Spunta" (3.6%) y "Ariana" (5.1%) y presentó la más baja variación el valor de a* (cerca de 50% vs 70% de todas las otras variedades). A 20°C "Safrane" y "Liseta" mostraron una disminución menor en L* (5.6 y 6.2%, respectivamente) y en los valores de ΔE (6.0 y 6.1, respectivamente), pero "Spunta" y "Ariana" fueron las variedades con las mayores disminuciones en estos parámetros. "Safrane" también recibió la calificación más alta en apariencia durante los primeros días de almacenamiento a ambas temperaturas, y tuvo un alto contenido de ácido ascórbico (31.2 mg/100g de peso fresco) y actividad antioxidante (26.6 mg TE/100 g de peso fresco). "Liseta" y

"Ariana" mostraron un potencial intermedio en términos de capacidad de almacenamiento y apariencia, mientras que "Spunta" fue la menos deseable para ser usada como corte fresco. Los resultados de este trabajo contribuyeron a aumentar el conocimiento de la conveniencia de las variedades de papa para ser procesadas en fresco, con lo que se pudiera surtir a la industria de corte fresco con material crudo deseable para procesamiento a lo largo del año, de acuerdo con la disponibilidad de la temporada.

Keywords Phenols · Browning · Ascorbic acid · Antioxidant activity · PPO activity

Introduction

Consumption of fresh-cut fruits and vegetables has grown rapidly in the last number of years as a result of the increase in consumer demand for products of high quality, convenience and freshness. Fresh-cut potatoes (peeled, sliced or diced, and packed) are considered to have commercial interest in the fresh-cut market as an alternative to pre-cooked or frozen potatoes. One of the main causes of quality deterioration in fresh-cut products is the enzymatic browning of the cut surfaces; this leads to a serious reduction in the marketable life. It is caused by the reaction between oxidative enzymes, such as polyphenol oxidase and/or phenol peroxidases, and their substrates (phenolic compounds) (Degl'Innocenti et al. 2005), coming into contact when the membranes within cells are damaged by minimal processing operations (Toivonen and Brummel 2008). The enzymes determine the hydroxylation of monophenols to o-diphenols and the oxidation of o-diphenols to o-quinones, that then polymerize into dark melanin pigments, that are responsible for a less attractive appearance and loss in nutritional quality (Tomás-Barberán and Espín 2001; Cantos et al. 2002). Important factors determining the rate of enzymatic browning in fruit and vegetables are the concentrations of active PPO and phenolic compounds (Martinez and Whitaker 1995), and the presence of antioxidants, such as ascorbic acid, that may control PPO activity through its ability to reduce quinones back to diphenols (Amiot et al. 1992; Nicolas et al. 1994).

In fresh-cut potatoes, enzymatic browning was found to be positively correlated with PPO activity and phenol content (Friedman 1997; Thybo et al. 2006, Cabezas-Serrano et al. 2009), in particular with tyrosine (Stevens and Davelaar 1997), chlorogenic, aspartic, and glutamic acids (Thybo et al. 2006).

Since the differences in content and types of phytochemicals (phenols and antioxidants) and in enzyme activity depend on variety, the browning susceptibility of fresh-cut potatoes may differ from cultivar to cultivar (Mattilia et al. 1993; Cantos et al. 2002; Cabezas-Serrano et al. 2009).

Cabezas-Serrano et al. (2009) reported that varieties characterized by a low phenol content and PPO activity, and high antioxidant activity and sugar content, also showed less color changes and lower incidence of browning . In their study on late varieties, 'Marabel' showed the best potential in terms of storability and appearance, followed by 'Agata', 'Vivaldi', and 'Agria', while 'Almera' was the least suitable to be used as fresh-cut, despite its high content in ascorbic acid and high antioxidant activity, most probably because of its high phenol content and PAL activity. Cantos et al. (2002) also found different browning susceptibilities in five potato varieties, with 'Agria' showing the best performances with respect to 'Cara', 'Monalisa', 'Spunta', and 'Liseta'.

The present study investigated the differences in the initial physical and chemical attributes, and in post-cutting behavior of four early potato cultivars. It was designed to give a further contribution to a previous study with winter potato varieties, gathering more information on cultivar suitability to be processed as fresh-cut product.

Material and Methods

Raw Material

In early June 2006, potato tubers (*Solanum tuberosum L.*) of four different cultivars, 'Ariana', 'Liseta', 'Safrane' and 'Spunta', were purchased from a local potato growers' association. They were stored at 10°C until processing in the Postharvest Laboratory of the University of Foggia.

Sample Processing and Storage Conditions

Tubers were washed in chlorinated water (100 ppm of free chlorine) in order to reduce surface contamination (Gorny 2001). Potatoes were then hand-peeled with a sharp knife, and cut into halves. One half of each tuber was frozen and used for chemical determinations at harvest. The other half was cut into 2-cm slices and then into cubes, with a commercial cutting grid. Cubes were immediately immersed in chlorinated water (100 ppm of free chlorine) for 2 min in order to prevent browning. Cutting operations were replicated three times for each variety, and for each replicate, nine groups of 15 cubes were obtained. One group was used for initial chemical evaluations, two groups were stored in perforated plastic clamshells at 5 and 20°C, respectively, and used for non-destructive evaluations, and six groups were used for destructive firmness measures after 0, 3 and 6 days of storage at 5°C and at 20°C. Non-destructive evaluations included color and general appearance and were performed after 0, 1, 2, 3, 6, and 8 days of storage at 5°C and 20°C.

Chemical Determination at Harvest

Vitamin C

Ten grams of fresh potato were homogenized with 10 mL of MeOH:H_2O (5:95) plus citric acid (21 g/L) with EDTA (0.5 g/L) and NaF (0.168 g/L). The homogenate was filtered through cheesecloth and C18 Bakerbond SPE cartridge (Baker, Deventer, Holland). Ascorbic acid (AA) and dehydroascorbic acid (DHAA) contents were determined as described by Zapata and Dufour (1992). The HPLC analysis was carried out after derivatization of DHAA into the fluorophore 3-(1,2-dihydroxyethyl) furol [3,4-b]quinoxaline-1-one (DFQ), with 1,2-phenylenediamine dihydrochloride (OPDA). 20 μL samples were analyzed with an HPLC (Agilent Technologies 1200 Series,Waldbronn, Germany) equipped with a DAD detector and a binary pump. Separations of DFQ and AA were achieved on a Zorbax Eclipse XDB- C18 column (150 mm×4.6 mm; 5 μm particle size; Agilent Technologies, Santa Clara, CA, USA). The mobile phase was MeOH:H_2O (5:95 v/v) containing 5 mM cetrimide and 50 mM potassium dihydrogen phosphate at pH 4.5. The flow rate was 1 mL/min. The detector wavelengths were 348 nm for DHA and 251 nm for AA.

Sugar Composition

For sugar composition, 5 g of frozen tissue were homogenized in 10 mL of pure water. Extracts were centrifuged at 12,000*g* for 5 min, filtered through C18 Bakerbond SPE cartridge (Baker, Deventer, Holland) and a 0.45 μm filter and injected into the HPLC system equipped with Refractive Index Detector (RID). The flow rate was 1 mL/min. Individual peaks were separated on an Alltima Amino (250 mm x 4.6 mm; 5 μm particle size; Alltech, Deerfield, IL, USA) quantified by comparison to standard solutions of glucose and sucrose and expressed as g/100 g of fresh weight (fw).

Total Phenol Content and Antioxidant Activity

The same extraction was conducted for both analyses, total phenols and antioxidant activity. Five grams of potato tissues were homogenized in 2 mM Sodium Fluoride methanol:water solution (80:20) for one minute, and then centrifuged at 5°C and 12,000*g* for 5 min. Total phenols were determined according to the method of Singleton and Rossi (1965). Each extract (100 μL) was mixed with 1.58 mL of water, 100 μL of Folin–Ciocalteau's reagent, and 300 μL of sodium carbonate solution (200 g/L). After 2 h, the absorbance was read at 575 nm against a blank in a spectrophotometer (Shimadzu UV-1700 l, Jiangsu, China). The total phenol content was calculated on the basis of the calibration curves of gallic acid, and was expressed as mg of gallic acid equivalents per 100 g of fresh weight (mg GAE/100 g fw). The antioxidant assay was performed following the procedure described by Brand-Williams et al. (1995), with minor modifications. The diluted sample (100 μL) was pipetted into 0.9 mL of DPPH solution to initiate the reaction. The absorbance was read after 15 min at 515 nm. Trolox was used as a standard and the antioxidant activity was reported in mg of Trolox equivalents per 100 g of fresh weight (mg TE/100 g fw).

PPO Activity

For PPO activity, 5 g of frozen tissue powder were homogenized in 30 mL of 0.1 M phosphate buffer pH:6 with 1 g of polyvinylpyrrolidone (PVP), and centrifuged at 12,000*g* for 15 min. The supernatant was used for PPO activity measurement to determine the absorbance increase at 410 nm over a period of 2 min at 25°C. The reaction mixture contained 1.5 mL of extract, 1 mL of phosphate buffer, and 0.5 mL of 100 mM 4-methylcatechol. The results were expressed as units of enzymatic activity. One unit of enzymatic activity was defined as the amount of the enzyme causing a change in absorbance of 0.01 in the initial linear region of the curves (15 s) (Kahn 1977).

Cube Evaluations at Harvest and during Storage

Overall Appearance Evaluation

Cubes were evaluated subjectively on a 5 to 1 scale, where 5=excellent, no defects, 4=very good, minor defects, 3=fair, moderate defects, 2=poor, major defects, 1=inedible. A score of 3 was considered as the limit of marketability and a score of 2 as the limit of edibility (Amodio et al. 2007). A group of four persons was employed to evaluate the general appearance of 15 cubes for each of the three replicates.

Color Evaluations

Color was measured on 15 potato cubes for each of the three replicates with a MINOLTA tristimulus colorimeter set with illuminant C (ΔE/°C=0.05), repeating the measurement 3 times.

L*a*b* parameters in the CIE scale were measured and Hue Angle=arctg $\frac{b^*}{a^*}$ and chromaticity = $\sqrt{a^{*2}+b^{*2}}$ were calculated. In addition, in order to compare samples with different initial color, ΔL*, Δa*, Δb* were calculated as% of the initial value, and ΔE was also calculated as $\sqrt{(L^*-L_0^*)^2+(a^*-a_0^*)^2+(b^*-b_0^*)^2}$.

Firmness

Firmness was measured on 10 potato cubes with an Instron Universal Testing machine, model 3340, measuring the maximum load necessary to cause the rupture of the cubes pressed between 2 parallel plates.

Statistical Analysis

Analysis of variance was performed on data of initial determinations in order to detect differences among cultivars. For each storage temperature, the analysis of variance (2-way ANOVA) was performed using a Split-Plot design considering the variety as the first factor and the time of storage as the second factor. The most conservative degrees of freedom were used to determine the effect of time, and of *variety X time* interaction. For each storage evaluation, the analysis of variance was focused only on the variety. Means were separated using the Tukey test.

Linear correlation coefficients (r) between parameters were calculated from the simple regression analysis between pairs of parameters; coefficients of determinations (r^2), which measure the variability explained by linear regression, were also determined and expressed as a percentage.

Results

Initial Color, Firmness and Chemical Composition

Some differences in chemical composition and color were found among potato cultivars. Color measurements just after cutting are reported in Table 1. Potato cultivars tested in this experiment had similar chromatic characteristics of the pulp. No significant differences were observed in lightness (L*), degree of yellowness (b*) and color saturation (chroma). 'Spunta' was characterized by a higher a* value (less negative) than 'Ariana' and 'Safrane', and also showed the lowest Hue Angle value (1.75). This result provided evidence of a slightly less greenish color of 'Spunta' compared with other cultivars. Firmness measured just after cutting varied from 159 N in 'Spunta' to 188 N in 'Ariana', but the differences within cultivars were not statistically significant (data not shown).

The potato cultivars showed variability in chemical parameters (Table 2).

Vitamin C content (AA+DHAA) was almost twice as high in 'Safrane' and 'Ariana' (55.9 and 51.0 mg/100 g fw) compared to 'Spunta' and 'Liseta' (24.9 and 31.8 mg/100 g fw), with the latter two varieties presenting the same proportion of ascorbic and dehydroascorbic acids. On the other hand, in 'Ariana' the oxidized form (DHAA) was prevalent (75% of the vitamin C), while in 'Safrane' a higher percentage of the reduced form (AA) was found (70% of the vitamin C).

Moreover, 'Safrane' showed the highest antioxidant activity (26.7 mg TE/100 g fw) and phenol content (37.9 mg GE/g fw), statistically different only from 'Liseta' (18.5 mg TE/100 g fw and 28.4 mg GE/g fw), whereas 'Ariana' presented the highest PPO activity (63.4 U/g fw). 'Spunta' had a glucose content that was statistically lower than 'Ariana' (2.47 vs 5.58 g/100 g fw, respectively) and also a sucrose content statistically higher than 'Ariana' and 'Safrane'(0.08 vs 0.03 and 0.04 g/100 g fw, respectively).

Effect of Variety on post-cutting Browning of Potato Cubes during Storage

Potato cubes exhibited changes in color and browning of the cut surfaces during storage, with the higher temperature speeding up these processes.

Table 3 reports the effect of cultivar and storage time, and of their interaction, on quality attributes of fresh-cut potatoes stored at 5 and 20°C, respectively.

All parameters associated with color changes were affected by cultivar and time at both storage temperatures, whereas firmness variation was dependent only on storage time. Cultivar influenced the overall appearance only at 20°C, but storage time affected this parameter at both temperatures.

Moreover, at 5°C, the *cultivar x time* interaction was not significant, showing that behavior patterns of each variety

Table 1 Initial color evaluation of four potato cultivars (mean values of 3 replicates ± standard deviation)

Color evaluations	Ariana	Liseta	Safrane	Spunta
L*	70.8±3.0 ns	69.4±3.1 ns	70.7±3.5 ns	69.7±2.8 ns
a*	−5.1±0.8 b	−4.7±0.7 ab	−5.0±0.5 b	−4.1±0.6 a
b*	22.6±3.9 ns	20.5±3.4 ns	20.8±2.5 ns	22.2±2.0 ns
Hue angle (%)	1.79±0.01 a	1.80±0.01 a	1.80±0.01 a	1.75±0.02 b
Chroma (%)	23.2±4.0 ns	21.0±3.5 ns	21.4±2.6 ns	22.6±2.0 ns

Within the same row, values followed by the same letter are not significantly different according to Tukey for $P \leq 0.05$; ns indicate no difference among the varieties

Table 2 Initial chemical composition of four potato cultivars (mean values of 3 replicates ± standard deviation)

Chemical composition	Ariana	Liseta	Safrane	Spunta
Ascorbic acid (mg/100 g fw)	14.5±1.9 b	24.7±0.4 a	31.2±3.4 a	13.1±0.6 b
Dehydroascorbic acid (mg/100 g fw)	41.4±7.3 a	19.9±8.3 b	19.8±1.3 b	11.8±0.4 b
Vitamin C content (mg/100 g fw)	55.9±7.4 a	31.8±7.8 ab	51.0±4.7 a	24.9±1.0 b
Antioxidant activity (mg TE/100 g fw)	23.4±4.5 ab	18.5±0.3 b	26.6±1.9 a	21.0±1.2 ab
Total phenolics (mg GE/100 g)	33.8±1.1 ab	28.4±0.8 b	37.9±2.0 a	37.8±5.6 a
PPO activity (U/g fw)	63.4±3.4 a	33.6±5.9 b	40.6±11.5 b	37.2±10.8 b
Glucose (g/100 g fw)	5.58±1.1 a	4.4±0.7 ab	5.1±1.3 ab	2.5±0.2 b
Sucrose (g/100 g fw)	0.03±0.003 b	0.07±0.014 a	0.04±0.001 b	0.08±0.008 a
Total soluble sugars (g/100 g fw)	5.60±1.1 ns	4.49±0.7 ns	5.16±1.3 ns	2.55±0.2 ns

Within the same row, values followed by the same letter are not significantly different according to Tukey for $P \leq 0.05$; ns indicate no difference among the varieties

were consistent over time, whereas at room temperature interactions were found for Δa*, ΔE and ΔHue Angle.

The main effect of the cultivar on quality attributes of potato cubes stored at 5 and 20°C is reported in Table 4, as mean values throughout the storage period.

At 5°C, overall appearance remained above the limit of marketability (score 3) for all cultivars, with no statistical differences among them, but a different behavior was observed for color changes. 'Safrane' showed a lower variation of a* (red component), Hue angle and, together with 'Liseta', of L* and ΔE values during 8 days of storage. Both these cultivars showed only about 1% variation in L*, thus demonstrating a lower loss in brightness compared with 'Spunta' (3.6%) and 'Ariana' (5.1%). Changes in a* value during storage were higher compared to changes in all other color parameters. 'Safrane' presented about 50% of variation in a* value compared to a Δa* exceeding 70% for all other cultivars. Variation in b* value was negative in 'Safrane' (−5.5%), indicating an increase in this parameter over time, followed by 'Ariana' (−1.4), while 'Spunta' and 'Liseta' showed positive variations (1.5 and 3.7%, respectively). Since b* values remained always positive during storage with low changes for all varieties (maximum 5.5% in 'Safrane'), the variation in this parameter only indicated a slight change in yellowness. The mean ΔE values, which summarize the overall color variations during storage, predominantly influenced by the changes in a* value, were 3.6 for 'Safrane', 4.3 for 'Liseta' and 'Spunta' and 6 for 'Ariana'.

Also at 20°C, all varieties were considered marketable and no differences were found among them in terms of overall appearance (Table 4), although in this case the mean score value was referred to a shorter storage time, since all samples almost reached score 1 after only 6 days. Storage at room temperature resulted in higher color changes (Table 4). Again 'Safrane' and 'Liseta' showed a lower decrease in L* and ΔE values, while 'Spunta' and 'Ariana' were the cultivars with the highest decrease in these parameters. For a* values, 'Spunta' showed 94.8% of variation, almost 25% higher than 'Liseta' and 'Safrane', and 40% higher than 'Ariana'. Firmness was not affected by the cultivar either at 5°C or at 20°C.

Score evaluation throughout storage is reported in Fig. 1.

The four varieties had different behavior during storage at both temperatures, although no differences were detected among them by the end of storage.

Table 3 Effect of cultivar, time of storage, and of *cultivar x time* interaction on appearance score, color and firmness changes of potato cubes stored at 5 and 20°C

	5°C			20°C		
	Cultivar	Time	Cultivar×Time	Cultivar	Time	Cultivar×Time
ΔL (%)	****	****	ns	****	****	ns
Δa (%)	****	****	ns	****	****	****
Δb (%)	***	****	ns	***	****	ns
ΔE	****	****	ns	****	****	**
ΔHue (%)	****	****	ns	****	****	***
ΔChroma (%)	***	****	ns	**	****	ns
ΔFirmness (N)	ns	*	ns	ns	*	ns
Score	ns	****	ns	**	****	ns

Within each row, each factor (cultivar and time) and their interaction are significantly different for $P \leq 0.05$ (*); $P \leq 0.01$ (**); $P \leq 0.001$ (***); $P \leq 0.0001$ (****); or non significant (ns)

Table 4 Effect of cultivar on appearance score and color changes of potato cubes stored at 5 and 20 °C (mean values of 3 replicates±standard deviation)

Temperature of storage	Quality parameters	Ariana	Liseta	Safrane	Spunta
5°C	ΔL (%)	5.1±3.6 a	0.9±2.1 b	1.5±2.2 b	3.6±1.9 a
	Δa (%)	71.2±26.1 a	72.7±23.2 a	52.1±20.6 b	75.9±27.0 a
	Δb (%)	−1.4±11.7 ab	3.7±9.3 a	−5.5±8.4 b	1.5±6.1 a
	ΔE	6.0±2.3 a	4.3±0.9 b	3.6±1.4 b	4.3±1.5 b
	ΔHue (%)	8.6±3.4 a	8.7±3.3 a	6.8±2.9 c	7.7±3.0 b
	ΔChroma (%)	0.7±11.3 ab	5.8±8.8 a	−3.4±7.7 b	2.9±5.8 a
	ΔFirmness (N)	1.7±13.7 ns	−3.2±9.8 ns	−1.2±4.4 ns	−2.1±5.6 ns
	Score	3.4±0.9 ns	3.5±0.9 ns	3.6±0.9 ns	3.3±0.9 ns
20°C	ΔL (%)	10.7±5.3 a	6.5±3.5 c	5.2±3.6 c	8.4±4.7 b
	Δa (%)	57.9±25.2 b	70.8±20.3 b	68.0±31.9 b	94.8±41.4 a
	Δb (%)	−8.4±15.4 b	−5.0±9.6 ab	−5.3±15.4 ab	0.3±13.7 a
	ΔE	9.1±3.7 a	6.1±2.5 c	6.0±2.9 c	7.6±3.8 b
	ΔHue (%)	7.8±2.7 c	9.1±2.4 bc	9.4±4.2 b	10.4±4.9 a
	ΔChroma (%)	−6.3±15.3 b	−2.7±9.5 ab	−2.9±15.1 ab	1.6±13.2 a
	ΔFirmness (N)	−8.9±17.5 ns	−20.5±16.3 ns	−13.5±10.8 ns	−10.0±5.8 ns
	Score	3.2±0.9 ns	3.2±1.0 ns	3.3±1.3 ns	3.0±1.1 ns

Within the same row, values followed by the same letter are not significantly different according to Tukey for $P \leq 0.05$; ns indicate no difference among the varieties

At 5°C, 'Safrane' was identified as the cultivar with the best appearance during the first 3 days, with a higher score value than 'Spunta', 'Liseta', and 'Ariana'. After 6 days, all the varieties received a score evaluation almost equal to the limit of marketability (score 3), except for 'Spunta' which was scored 2.5; after 8 days all of them reached the limit of edibility (score 2).

At room temperature, once again 'Safrane' was scored significantly better than the other varieties during the first 2 days of storage; on the contrary 'Spunta' could be identified as the cultivar with the worst appearance up to day 3, while at day 6 all the varieties were scored below the limit of edibility.

Changes in a* value during storage are reported in Fig. 2. At 5°C, Δa* reached a positive variation of about 90% for all varieties after 8 days of storage, except for 'Safrane' which only showed a 70% variation from the initial value. At room temperature, all varieties showed about 50% of a* variation after only 1 day, while later during storage, 'Spunta' showed a significantly different behavior, with a Δa* value of 150% vs. 100% of the other varieties at day 6.

ΔE value represents the difference in the measurements between two colors and it is considered perceptible to human eyes when ranging from 4 to 6 (CIE 2004). In this study ΔE was calculated as the difference between the color measured just after cutting and the color measured at the end of storage. Differences in ΔE value among cultivars were evident after 2 days of storage at 20°C and after 6 days at 5°C (Fig. 3). At 5°C all varieties resulted in visible changes after 3 days of storage, except for 'Safrane' which showed a ΔE value of 3.7. At 20°C, 'Ariana'

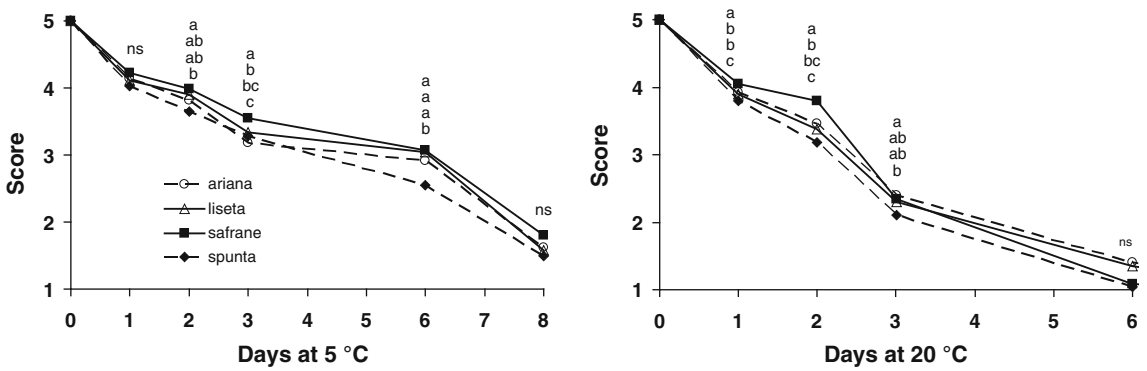


Fig. 1 Appearance score of potato cubes of different cultivars stored at 5 and at 20°C, mean values of 3 replicates. Within the same storage time, values with the same letter are not significantly different according to Tukey for $P \leq 0.05$; ns indicate no difference among the varieties

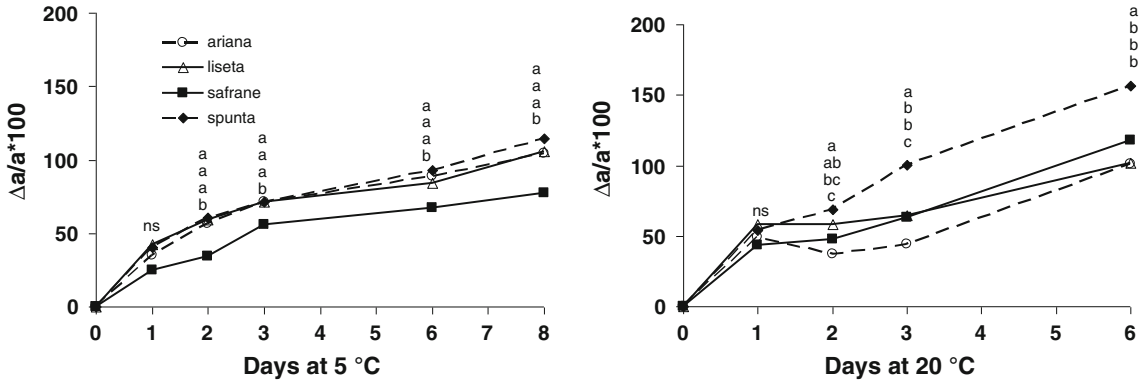


Fig. 2 Percent variation of a* value (Δa*) of potato cubes of different cultivars stored at 5 and at 20°C, mean values of 3 replicate. Within the same storage time, values with the same letter are not significantly different according to Tukey for $P \leq 0.05$; ns indicate no difference among the varieties

showed a considerable change in color after just 1 day, followed by the other varieties after 2 days of storage.

Correlations between Parameters

In Table 5 correlation (r) and determination (r^2) coefficients between parameters are reported. Antioxidant activity showed significant positive correlation with total phenols (r=0.64) and vitamin C content (r=0.74), confirming that both these factors contribute to the antioxidant capacity in potato samples, with 41.5 and 55.7% of the variation in antioxidant activity explained by the variation in phenols and vitamin C, respectively. Score evaluation was highly negatively correlated with a* value variation (Δa*) at both storage temperatures (r=−0.85 at 5°C, and r=−0.76 at 20°C), indicating that the score attributed to the samples during storage was very dependent on the evolution of a* value.

Vitamin C content was found to be negatively correlated with Δa* (r=−0.83 at 20°C, and r=−0.47 at 5°C) and positively with score evaluation (r=0.43 at 20°C, r=0.73), although the correlations were significant only for samples stored at 20°C. These correlations indicate that samples with higher vitamin C content showed a lower change in a* value, and also received a better evaluation for overall appearance.

PPO activity showed a significant positive correlation coefficient with ΔE value (r=0.64 at 20°C, and r=0.57 at 5°C), significant for samples stored at higher temperature, and a significant negative correlation with Δa* (r=−0.6) only in the case of storage at 20°C. No correlations were found between PPO activity and score evaluation, and between phenol content and all the other parameters.

Discussion

The potato cultivars tested in this experiment showed differences in terms of chemical attributes, evident upon cutting, and in different changes in color and appearance during post-cutting storage at 5 and 20°C (Tables 1, 2, and 4). Other authors have previously reported a broad variation among potato varieties for browning susceptibility (Mattilia et al. 1993; Cabezas-Serrano et al. 2009). In this study,

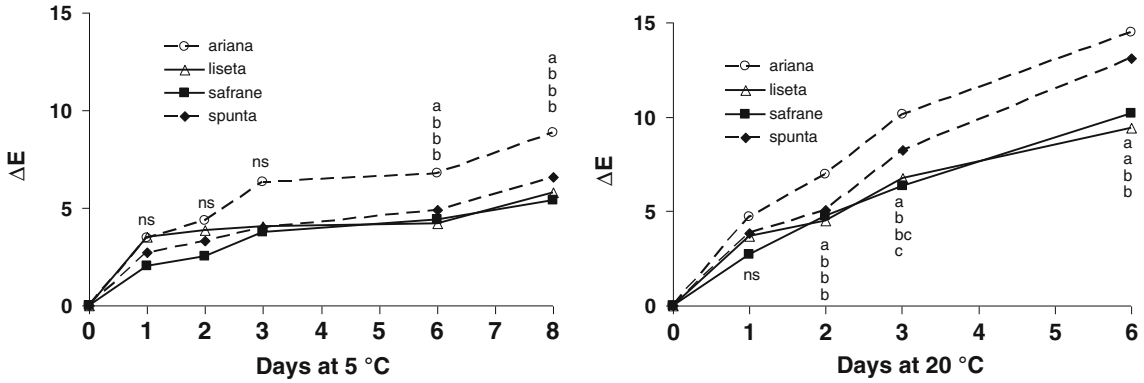


Fig. 3 Overall color variation (ΔE) of potato cubes of different cultivars stored at 5 and at 20°C, mean values of 3 replicate. Within the same storage time, values with the same letter are not significantly different according to Tukey for $P \leq 0.05$; ns indicate no difference among the varieties

Table 5 Coefficient of correlation (above diagonal) and coefficient of determination (in%, below diagonal) between monitored parameters, statistically significant for $P \leq 0.05$ (*); $P \leq 0.01$ (**); $P \leq 0.001$ (***)

	AOX	Phenols	VitC	PPO	Δa_5	ΔE_5	Score 5	Δa_20	ΔE_20	Score 20
AOX	–	0.64 *	0.74 **	0.28	−0.47	0.17	0.34	−0.33	−0.05	0.36
Phenols	41.50	–	0.18	0.05	−0.17	0.01	−0.18	0.29	0.11	−0.17
VitC	55.70	3.30	–	0.55	−0.47	0.37	0.43	−0.83 ***	0.11	0.73 **
PPO	7.78	0.24	30.40	–	−0.01	0.57	0.12	−0.60 *	0.64 *	0.10
Δa_5	22.10	2.90	21.89	0.03	–	−−0.85 ***		–	–	–
ΔE_5	11.30	8.45	13.36	32.92	–	–	−0.44	–	–	–
Score 5	3.10	0.00	19.03	1.46	72.55	19.91	–	–	–	–
Δa_20	0.23	1.14	68.97	35.86	–	–	–	–	–	−0.76 **
ΔE_20	11.30	3.50	1.21	42.01	–	–	–	–	–	−0.01
Score 20	12.70	2.78	48.44	1.12	–	–	–	57.99	0.01	–

'Safrane' was identified as the cultivar with the best appearance during the first days of storage with lesser color changes. 'Ariana' and 'Liseta' also showed good performance, whereas 'Spunta' proved to be the least suitable as a fresh-cut product. These results can be explained by differences in composition within varieties, particularly in antioxidant content and enzyme activity.

'Safrane' showed a high ascorbic acid content and antioxidant activity which could have contributed to a reduction in the effects of the oxidative reactions, despite its high initial phenol content. In addition, PPO activity for this cultivar was relatively low. Several authors attributed the high ascorbic acid content of different vegetable species to a delay of the browning phenomena (Campos-Vargas et al. 2005; Degl'Innocenti et al. 2005; Heimdal et al. 1995; Reyes et al. 2007). In fact, vitamin C is a well-known reducing agent that might be involved in the prevention of melanin formation due to its capacity to convert o-quinones back to diphenols (Amiot et al. 1992; Nicolas et al. 1994). Moreover, vitamin C may also inhibit PPO action by decreasing the pH to values below the optimum for its activity (pH 5–7), and by chelating metal ions and/or reducing the availability of oxygen, which are both needed to oxidize phenols (Vamos-Vigyazo 1981). In the present study, the high phenol content of 'Safrane' did not result in a worsening of general appearance, confirming the findings of other authors on browning which is not necessarily related to phenolic content (Couture et al. 1993; Cantos et al. 2002). According to Cantos et al. (2002), membrane stability may be the limiting factor in cut potatoes, delaying the contact between PPO enzyme and substrates. Finally, the different type of phenols in the potato varieties studied, could have lead to a lower affinity to the PPO enzyme. In fact, some authors have reported a positive correlation between tyrosine and chlorogenic acid with PPO activity (Friedman 1997; Thybo et al. 2006); in contrast, Thybo et al. (2006) found a negative correlation between caffeic acid and enzymatic discoloration in pre-peeled potato.

'Ariana' and 'Liseta' presented an intermediate behavior in terms of general appearance preservation, but they had some differences in initial chemical composition and color changes. 'Ariana' showed the highest PPO activity and a relatively high phenol content, but it did not exhibit a more severe browning than other varieties. Most probably its high vitamin C content might have ensured a protection against oxidation. In fact, most of the AA content in this variety was in the oxidized form that could indicate a self-oxidation which prevented the oxidation of phenol compounds (Mayer and Harel 1979). In addition, a high membrane stability, as already explained (Cantos et al. 2002), may explain the good performance of this variety. 'Liseta' showed quite high ascorbic acid content, but also lower phenol content and PPO activity; all these factors contributed to the relatively good performance of this cultivar.

'Spunta', that in many cases was identified as the cultivar with the worst appearance, showed the lowest ascorbic acid content, a value for PPO activity similar to 'Liseta' and 'Safrane', but also a higher phenol content, resulting in a lower resistance to browning.

As for the research of possible correlations, total phenol content did not correlate either with appearance score or color changes, confirming that browning may not be necessarily related to phenolic content as previously found by Cantos et al. (2002). PPO activity was positively correlated with ΔE, indicating that samples with high enzyme activity also showed high variation in overall color. Score evaluation was negatively correlated with Δa* value, whereas no correlation was found with the overall color change (ΔE), indicating that appearance during storage was very dependent on the evolution of a* value. This result matches the findings of several authors reporting a correlation between browning score and a* value, as in fresh-cut iceberg lettuce (Heimdal et al. 1995; Peiser et al. 1998). Moreover, a* value was the color parameter with the highest change during storage (70–90% at 5°C and 100–150% at 20°C) compared to changes in the other color

attributes. For these reasons, the variation of the red component (Δa*) seems to be the best indicator of browning manifestation among all color attributes.

Antioxidant activity was correlated both with ascorbic acid content and total phenols, indicating their antioxidant function in potato samples, whereas no correlation was found between phenols and PPO activity. Also in a previous study (Cabezas-Serrano et al. 2009), antioxidant activity was correlated more with ascorbic acid content than with total phenols, but the latter were well correlated with PPO; the phenolic contribution to oxidative reaction was more decisive than its antioxidant role. As mentioned before, the lack of correlation between PPO activity and phenols observed in this study may be due to a different type of phenols with a lower affinity for the PPO enzyme. Potato varieties used in this study showed a higher Vitamin C content compared to varieties used in other works (Finotti et al. 2006; Cabezas-Serrano et al. 2009). Vitamin C was correlated with a* value variation and appearance score during post-cutting storage: varieties with a higher total ascorbic acid content ('Safrane') also showed a lower Δa* value and a better appearance during storage, confirming the anti-browning activity of this compound.

Conclusion

The evaluation of the suitability of a potato cultivar to be processed as a fresh-cut product represents the first step in order to obtain a final product with excellent quality. Results of this work contribute to an increase in knowledge on the suitability of potato cultivars to be processed as fresh cut produce. In addition to results obtained in a previously published screening on late potato varieties, this study may help to supply the fresh-cut industry with raw materials suitable for processing throughout the year, according to seasonal availability. Further studies may be aimed at extending the screening to other varieties and at the eventual use of additional technologies in order to delay the browning process.

References

Amiot, M.J., M. Tacchini, S. Aubert, and J. Nicolas. 1992. Phenolic composition and browning susceptibility of various apple cultivars at maturity. *Journal of Food Science* 4: 958–962.

Amodio, M.L., A.B. Cabezas-Serrano, R. Rinaldi, and G. Colelli. 2007. Implementation of rating scales for visual quality evaluation of various vegetable crops. In *Produce quality rating scales and color charts., Postharvest horticulture series NO. 23*, ed. A.A. Kader and M. Cantwell. CA-USA: University of California, Davis.

Brand-Williams, W., M.E. Cuvelier, and C. Berset. 1995. Use of a free radical method to evaluate antioxidant activity. *Lebensmittel-wissenschaft Technology* 28: 25–30.

Cabezas-Serrano, A.B., M.L. Amodio, R. Cornacchia, R. Rinaldi, and G. Colelli. 2009. Suitability of five different potato cultivars (*Solanum tuberosum* L.) to be processed as fresh-cut products. *Postharvest Biology and Technology* 53: 138–144.

Campos-Vargas, R., H. Nonogaki, T. Suslow, and M.E. Saltveit. 2005. Heat shock treatments delay the increase in wound-induced phenylalanine ammonia-lyase activity by altering its expression, not its induction in Romaine lettuce *(Lactuca sativa*) tissue. *Physiologia Plantarum* 123: 82–91.

Cantos, E., J.A. Tudela, M.I. Gil, and J.C. Espín. 2002. Phenolic compounds and related enzymes are not rate-limiting in browning development of fresh-cut potatoes. *Journal of Agricultural and Food Chemistry* 50: 3015–3023.

CIE. 2004. *Colorimetry, CIE Pb. 15:2004*, 20–21. Vienna: Central Bureau of the CIE.

Couture, R., M.I. Cantwell, D. Ke, and M.E. Saltveit. 1993. Physiological attributes related to quality attributes and storage life of minimally processed lettuce. *Hortscience* 58: 609–610.

Degl'Innocenti, E., L. Guidi, A. Paradossi, and F. Tognoni. 2005. Biochemical study of leaf browning in minimally processed leaves of lettuce (*Lactuca sativa* L. var. Acephala). *Journal of Agricultural and Food Chemistry* 52: 9980–9984.

Finotti, E., A. Bertone, and V. Vivanti. 2006. Balance between nutrients and anti-nutrients in nine Italian potato cultivars. *Food Chemistry* 99: 698–701.

Friedman, M. 1997. Chemistry, biochemistry and dietary role of potato polyphenols. A review. *Journal of Agricultural and Food Chemistry* 45: 1523–1540.

Gorny J.R. 2001. *Food safety guidelines for the fresh-cut industry*, 4th edition. International Fresh-cut Produce Association.

Heimdal, H., B.F. Kuhn, L. Poll, and L.M. Larsen. 1995. Biochemical changes and sensory quality of shredded and MA-package iceberg lettuce. *Journal of Food Science* 60: 1265–1268.

Kahn, V. 1977. Some biochemical properties of phenol oxidase from two avocado varieties differing in their browning rates. *Journal of Food Science* 42: 38–43.

Martinez, M.V., and J.R. Whitaker. 1995. The biochemistry and control of enzymatic browning. *Food Science & Technology* 6: 195–200.

Mattilia, M., R. Ahvenainen, and E. Hurme. 1993. Prevention of browning of pre-peeled potato. In *COST 94, Proc. Workshop "System and operation for post-harvest quality"*, eds. J. De Baerdemaker, et al. Leuven, Belgium.

Mayer, A., and E. Harel. 1979. Polyphenol oxidases in plants. *Phytochemistry* 18: 193–215.

Nicolas, J.J., F.C. Richard-Forget, P.M. Goupy, M.J. Amiot, and S.Y. Aubert. 1994. Enzymatic browning reactions in apple and products. *Critical Reviews in Food Science and Nutrition* 34: 109–157.

Peiser, G., G. López-Gálvez, M. Cantwell, and M.E. Saltveit. 1998. Phenylalanine ammonia lyase inhibitors control browning of cut lettuce. *Postharvest Biology and Technology* 14(2): 171–177.

Reyes, L.F., J.E. Villareal, and L. Cisneros-Zevallos. 2007. The increase in antioxidant capacity after wounding depends on the type of fruit or vegetable tissues. *Food Chemistry* 101: 1254–1262.

Singleton, V.L., and J.A. Rossi. 1965. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture* 16: 144–158.

Stevens, L.H., and E. Davelaar. 1997. Biochemical potential of potato tubers to synthesize blackspot pigments in relation to their actual blackspot susceptibility. *Journal of Agricultural and Food Chemistry* 45: 4221–4226.

Thybo, A.K., J. Christiansen, K. Kaack, and M.A. Petersen. 2006. Effect of cultivars, wound healing and storage on sensory quality and chemical components in pre-peeled potatoes. *Lebensmittel-wissenschaft Technology* 39: 166–176.

Toivonen, P.M.A., and D.A. Brummel. 2008. Review. Biochemical bases of appearance and texture changes in fresh-cut fruit and vegetables. *Postharvest Biology and Technology* 48: 1–14.

Tomás-Barberán, F.A., and J.C. Espín. 2001. Phenolic compounds and related enzymes as determinants of quality in fruits and vegetables. *Journal of the Science of Food and Agriculture* 81: 853–876.

Vamos-Vigyazo, L. 1981. Polyphenol oxidase and peroxidase in fruits and vegetables. *CRC Critical Reviews in Food Science and Nutrition* 15: 49–127.

Zapata, S., and J.F. Dufour. 1992. Ascorbic, dehydroascorbic and isoascorbic acid simultaneous determinations by reverse phase ion interaction HPLC. *Journal of Food Science* 57: 506–511.

4.3. SCREENING QUALITY AND BROWNING SUSCEPTIBILITY OF FIVE ARTICHOKE CULTIVARS FOR FRESH-CUT PROCESSING. JOURNAL OF THE SCIENCE OF FOOD AND AGRICULTURE 89, 2588-294 (2009)

Research Article

Received: 16 June 2009 Revised: 31 July 2009 Accepted: 4 August 2009 Published online in Wiley Interscience: 28 September 2009

(www.interscience.wiley.com) DOI 10.1002/jsfa.3759

Screening quality and browning susceptibility of five artichoke cultivars for fresh-cut processing

Ana B Cabezas-Serrano, Maria L Amodio, Rosaria Cornacchia, Raffaella Rinaldi and Giancarlo Colelli*

Abstract

BACKGROUND: Artichoke is a rich source of bioactive compounds, mainly phenols, in the Mediterranean diet, but its consumption is limited by the complexity of time-consuming trimming operations. Fresh-cut processing would therefore add convenience to its consumption, even though the severity of post-cutting browning of artichoke pieces is still a major problem. Since susceptibility to browning may vary widely among genotypes, the choice of the cultivar is a very critical step in the fresh-cut process. In this study, five different Italian cultivars (C3, Catanese, Tema, Violetto Foggiano and Violetto Sardo) were screened for their initial quality and composition, and their post-cutting performance during storage at 5 °C and 20 °C.

RESULTS: C3 showed the highest phenol content (3.4 g GA kg^{-1}) and antioxidant activity (24.5 mmol L^{-1} kg^{-1}), but the worst quality in terms of appearance and colour changes, also due to its high PPO activity (62.2 U g^{-1}). Catanese showed the highest vitamin C content (117.7 mg kg^{-1}), the lowest phenol content (1.8 g GA kg^{-1}), and the best post-cutting quality. Tema, Violetto Foggiano and Violetto Sardo showed an intermediate phenol content, the latter showing the lowest appearance score after C3.

CONCLUSION: These results confirmed the role of phenols in browning processes of fresh-cut artichokes, giving the first available information on artichoke cultivar suitability to be processed as a fresh-cut product.

Keywords: phenols; browning; ascorbic acid; antioxidant activity; PPO activity

INTRODUCTION

Artichokes are an important component of the Mediterranean diet, and a good source of health-promoting compounds, mainly polyphenols, composed of mono- and dicaffeoylquinic acids, and flavonoids.[1–4] *In vivo* and *in vitro* studies with artichoke plants showed hepatoprotective functions, the inhibition of cholesterol biosynthesis in hepatocytes, diuretic, anti-inflammatory and anti-microbial properties.[5,6] The edible fraction of artichoke plants (*Cynara scolymus* L.) is represented by the inner part of immature flowers (heads, buds or capitula), which accounts for about 15–20% of its fresh weight, depending on the variety and the harvesting time, and about 50% of the whole head.[2] The high percentage of discarded portion, together with the complex and time-consuming trimming operations, make artichoke processing as a fresh-cut product very convenient. In addition, since receptacles and inner bracts contain the highest phenol levels,[7,8] fresh-cut artichokes may represent a 100% high nutritional edible portion. On the other hand, it is well known that the dual role of phenol compounds as antioxidants and as substrates for oxidative enzymatic and non-enzymatic browning reactions,[7,9,10] may cause a severe shelf-life reduction of both whole and fresh-cut products. Browning is, in fact, one of the major quality concerns for fresh-cut artichoke products, and is correlated with its high phenol content[10] that may vary qualitatively and quantitatively according to the genotype. Several authors, in fact, reported a different phenol content and composition, and antioxidant activity among heads or leaves of artichoke varieties.[8,11] Wang *et al.*[11] indicated that Imperial Star and Green Globe artichoke leaves contained significantly higher total phenols and cynarin content, and antioxidant activity, than Violet variety. For other species, the susceptibility to browning was found to differ from cultivar to cultivar, as for fresh-cut peaches,[12] pears[13] and potatoes,[14] whereas such information is not available for artichokes.

Previous studies on artichokes reported the effect of storage temperature on vitamin C and phenol content in whole heads,[15] the characterisation of phenol components,[7,8,11,12] and antioxidant activity of phenolic fractions.[10,17,18]

Objective of the present work was to investigate differences in the initial quality, in terms of physical and chemical attributes, and shelf life, of fresh-cut artichokes from five widely grown Italian cultivars, C3, Catanese, Tema, Violetto Foggiano and Violetto Sardo, in order to gather valuable information on cultivar suitability to be processed as fresh-cut product.

* *Correspondence to: Giancarlo Colelli, Dip. PRIME, Università degli Studi di Foggia, Via Napoli 25, 71100 Foggia, Italy. E-mail: g.colelli@unifg.it*

Dip. PRIME, Università degli Studi di Foggia, Via Napoli 25, 71100 Foggia, Italy

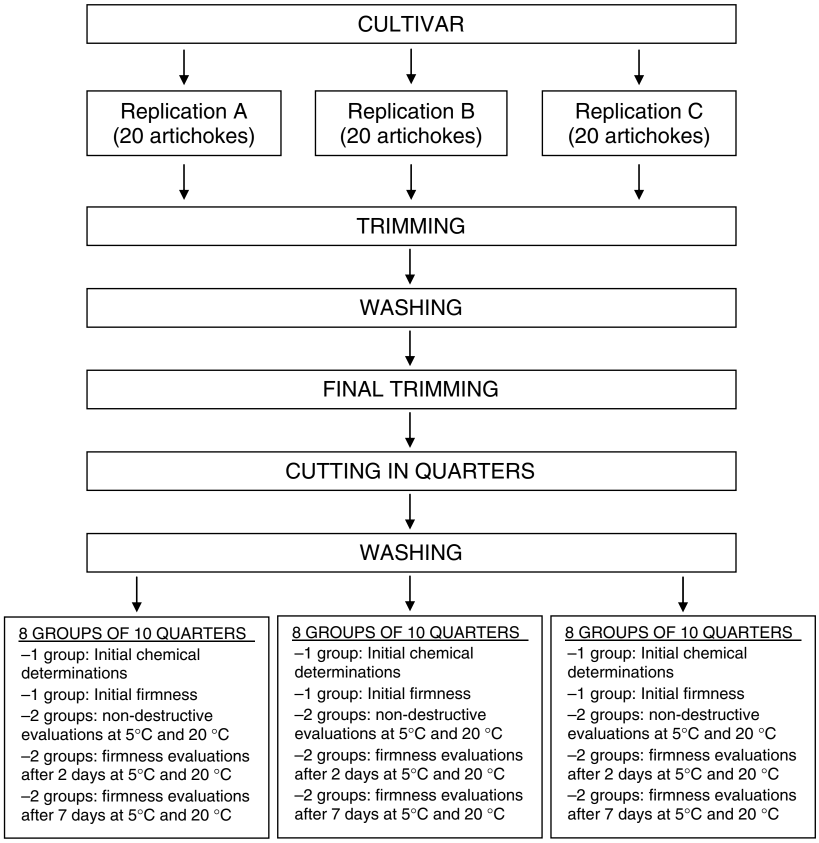


Figure 1. Scheme of processing operations for a single cultivar of fresh-cut artichokes.

EXPERIMENTAL

Raw material, handling and storage

Two white cultivars of artichokes, C3 and Catanese, and three violet cultivars, Tema, Violetto Foggiano and Violetto Sardo, grown in the same farm of southern Italy, were harvested in April, when they reached commercial maturity (defined by the compactness of fully developed buds), and transported to the Postharvest Laboratory at the University of Foggia. Artichoke buds were processed on the same day in a cold room at 10 °C under suitable hygienic conditions. All bench surfaces, utensils and plastic containers were washed with sodium hypochlorite. Twenty artichokes for each cultivar replication were processed as shown in Fig. 1. Artichokes were hand trimmed using sharp stainless steel knives in order to remove external bracts, leaves and stalks; heads were then washed in a NaOCl solution (100 ppm of free chlorine) to eliminate residues of soil and insects. After washing, head trimming was completed by further removing external greener and tougher bracts (inedible fraction) so as to keep just the innermost tender bracts. Artichoke hearts were then cut in quarters, for a total of eight groups of 10 quarters, and immediately immersed in a NaOCl solution. Two groups were stored in perforated plastic clamshell at 5° and at 20 °C, respectively, and used for non-destructive evaluations. A few layers of paper towels were placed on top of each clamshell and kept wet throughout the experiment in order to maintain a high degree of RH within the containers. One group was used for initial chemical evaluations, and six groups were used for destructive firmness measures after 0, 2 and 7 days of storage at 5 °C and 20 °C. All these steps were replicated three times for each cultivar.

Non-destructive evaluations included colour and general appearance and were performed after 0, 2, 5 and 7 days of storage at 5 °C and 20 °C.

Evaluation of general appearance

Quarters were evaluated subjectively on a scale of 5 to 1, where 5 = excellent, no defects; 4 = very good, minor defects; 3 = fair, moderate defects; 2 = poor, major defects; and 1 = inedible. A score of 3 was considered as the limit of marketability and a score of 2 as the limit of edibility.[19]

Colour determinations

Colour was measured on three different points on the receptacle, with a MINOLTA tristimulus colorimeter, testing L^*, a^* and b^* parameters in the CIE L^*a^*b scale and calculating the hue angle as

$$\mathrm{arctg}\; b^*/a^*$$

and chromaticity as

$$\sqrt{a^{*2} + b^{*2}}.$$

In addition, in order to comparing samples with different initial colours, ΔL^*, Δa^* and Δb^* were calculated as % of initial variation, and ΔE was calculated as

$$\sqrt{(L^* - L_0{}^*)^2 + (a^* - a_0{}^*)^2 + (b^* - b_0{}^*)^2}.$$

Determination of firmness

Firmness was measured as the maximum cutting force required by a single blade to cut through the middle of a whole quarter.

A digital firmness tester (Tierre s.r.l., Turin, Italy), equipped with a hand-manufactured shear blade (cross-surface of 60 mm^2) was used. In order to compare samples with different initial firmness, % of initial firmness variation was calculated.

Analysis of vitamin C

Ten grams of fresh weight sample were homogenised in an Ultraturrax (IKA, T18 Basic; Wimington, NC, USA) for 1 min with 10 mL of extraction medium (MeOH/H_2O (5 : 95), plus citric acid (21 g L^{-1}), EDTA (0.5 g L^{-1}) NaF (0.168 g L^{-1}). The homogenate was filtered through cheesecloth and the pH adjusted to 2.2–2.4 by addition of 1 mol L^{-1} HCl. The homogenate was centrifuged at 10 000 rev^{-1} for 5 min and the supernatant was recovered, filtered through a C18 Sep-Pak cartridge (Waters, Milford, MA, USA) and then through a 0.45 µm polyethersulfone filter. Ascorbic acid (AA) and dehydroascorbic acid (DHA) contents were determined as described by Zapata and Dufour.[20] The HPLC analysis was achieved after derivatisation of DHA into the fluorophore 3-(1,2-dihydroxyethyl) furol [3,4-*b*]quinoxaline-1-one (DFQ), with 1,2-phenylenediamine dihydrochloride (OPDA). Samples of 20 µL were analysed with an HPLC (Agilent Technologies 1200 Series; Agilent, Waldbronn, Germany) equipped with a DAD detector and a binary pump. Separations of DFQ and AA were achieved on a Zorbax Eclipse XDB- C18 column (150 mm × 4.6 mm; 5 µm particle size; Agilent Technologies, Santa Clara, CA, USA). The mobile phase was MeOH/H_2O (5 : 95 v/v) containing 5 mmol L^{-1} cetrimide and 50 mmol L^{-1} potassium dihydrogen phosphate at pH 4.5. The flow rate was 1 mL min^{-1}. The detector wavelengths were 348 nm for DHA and 251 nm for AA. AA and DHA contents were expressed as mg of ascorbic or dehydroascorbic acid per kg of fresh weight (mg kg^{-1}). In addition, the DHA/vitamin C ratio was calculated.

Total phenol content and antioxidant activity

The same extraction was carried out for the analyses of total phenols and antioxidant activity. Five grams of artichoke tissues were homogenised in 2 mmol L^{-1} NaF methanol : water solution (80 : 20) for 1 min, and then centrifuged at 5 °C and 12 000 rev^{-1} for 10 min. The pellet was discarded and the supernatant was retained and used as extract. Total phenols were determined according to the method of Singleton and Rossi.[21] Each extract (100 µL) was mixed with 1.58 mL water, 100 µL of Folin–Ciocalteau reagent and 300 µL of sodium carbonate solution (200 g L^{-1}). After 2 h standing, the absorbance was read at 575 nm against a blank, with a spectrophotometer (UV-1700; Shimadzu, Jiangsu, China). The total phenol content was calculated on the basis of the calibration curves of gallic acid, and expressed as mg of gallic acid equivalents per kg of fresh weight (g GA kg^{-1}).

The antioxidant assay was performed following the procedure described by Brand-Williams *et al.*,[22] with minor modifications. The diluted sample (100 µL) was pipetted into 0.9 mL of DPPH solution to start the reaction. The absorbance was read after 15 min at 515 nm. Trolox was used as a standard and the antioxidant activity was reported in mg of Trolox equivalents per kg of fresh weight (mmol TE kg^{-1}).

PPO activity

For polyphenol oxidase (PPO) activity, 5 g of frozen tissue powder were homogenised in 30 mL of 0.1 mol L^{-1} phosphate buffer (pH 6) containing 1 g of polyvinylpyrrolidone (PVP), and centrifuged at 12 000 rev^{-1} for 15 min. The supernatant was used for PPO activity, measured by determining the absorbance increase at 410 nm over a period of 2 min at 25 °C. The reaction mixture contained 1.5 mL of extract, 1 mL of phosphate buffer, and 0.5 mL of 100 mmol L^{-1} 4-methylcatechol. The results were expressed as units of enzymatic activities. One unit was defined as the amount of the enzyme which caused a 0.01 change in absorbance in the first 15 s, which were within the first linear region of each curve.[23]

Table 1. Initial composition of five artichoke cultivars

Chemical composition	C3	Catanese	Tema	Violetto Foggiano	Violetto Sardo
Total phenols (gGA kg^{-1})	3.4^{a}	1.8^{b}	3.1^{ab}	2.5^{ab}	2.3^{ab}
Ascorbic acid (mg kg^{-1})	19.9^{b}	21.5^{b}	36.2^{a}	33.4^{a}	26.7^{b}
Dehydroascorbic acid (mg kg^{-1})	59.2^{ab}	95.5^{a}	20.6^{b}	69.7^{ab}	38.2^{b}
Vitamin C (mg kg^{-1})	79.1^{ab}	117.7^{a}	56.6^{b}	103.2^{ab}	61.2^{b}
DHAI vitamin C	7.5^{ab}	8.1^{a}	3.6^{c}	6.8^{b}	6.2^{b}
Antioxidant activity (mmol L^{-1} TEAC kg^{-1})	24.5^{a}	16.6^{ab}	7.2^{b}	21.5^{ab}	17.1^{ab}
PPO activity (U g^{-1})	62.2^{a}	54.6^{ab}	41.6^{abc}	27.7^{bc}	23.2^{c}

Within the same row, values followed by the same letter are not significantly different, $P \leq 0.05$.

Statistical analysis

On initial data, and for each storage time, the effect of the cultivar was tested performing a one-way ANOVA, with data means arranged in a completely randomised design. For each storage temperature, a two-way ANOVA was performed using a split-plot design considering the cultivar as the first factor and the time of storage as the second factor. The most conservative degrees of freedom were used to determine the effect of time, and cultivar × time interaction. Means were separated using the Tukey test ($P = 0.05$).

RESULTS

Effect of cultivar on initial quality of fresh-cut artichokes

Several differences in terms of composition and colour were found among artichoke cultivars. The effect of the cultivar on the initial composition, antioxidant and enzymatic activities, is reported in Table 1. Phenol content ranged from 1.8 g GA kg^{-1} in Catanese to 3.4 g GA kg^{-1} in C3. Moreover, C3 had the highest PPO activity (62.2 U g^{-1}) and antioxidant activity (24.5 mmol L^{-1} TE kg^{-1}), statistically different only from Tema (7.2 mmol L^{-1} TE kg^{-1}), which showed a very low antioxidant activity compared to the other cultivars. Tema, together with Violetto Sardo, gave the lowest vitamin C content (56.6 mg kg^{-1}), which was about half of the content found in Catanese, which proved to be the richest cultivar in vitamin C content (117.7 mg kg^{-1}) in both reduced and oxidised forms, with the highest DHA/vitamin C percentage.

As for colour and firmness, C3, Tema, and Catanese were the cultivars showing extreme values for most of the measured attributes, as reported in Table 2. Hue angle values indicated a yellow colour of the artichoke cut surfaces ranging from 89.6 in Tema to 94.0 in C3 which was therefore characterised by a

Table 2. Initial colour and firmness of five artichoke cultivars

Parameter	C3	Catanese	Tema	Violetto Foggiano	Violetto Sardo
L^*	78.0^{ab}	79.9^{a}	75.5^{b}	77.1^{ab}	76.9^{ab}
a^*	−2.0^{c}	−0.7^{ab}	0.2^{a}	−1.2^{bc}	−0.4^{ab}
b^*	28.8^{a}	26.8^{b}	27.7^{ab}	27.3^{b}	27.0^{b}
Hue angle (°)	94.03^{a}	91.50^{bc}	89.65^{c}	92.43^{ab}	90.92^{bc}
Chroma	28.9^{a}	26.8^{b}	27.7^{ab}	27.3^{b}	27.0^{b}
Firmness (N)	72.7^{a}	55.0^{b}	57.7^{ab}	63.7^{ab}	59.0^{ab}

Within the same row, values followed by the same letter are not significantly different, $P \leq 0.05$.

Table 3. Effect of cultivar, time of storage, and of the cultivar × time interaction on appearance evaluation (score), firmness and colour of artichoke quarters stored at 5 °C and 20 °C

	5 °C			20 °C		
Parameter	Cultivar	Time	Cv × time	Cultivar	Time	Cv × time
ΔL (%)	****	****	ns	****	****	ns
Δa (%)	***	ns	ns	****	ns	ns
Δb (%)	****	****	*	****	***	*
Δhue (%)	****	****	*	****	ns	ns
Δchroma (%)	****	****	ns	****	***	ns
ΔE	****	****	ns	****	****	ns
Score	****	****	***	****	****	****
Δfirmness (N)	ns	ns	ns	*	ns	ns

**** $P \leq 0.0001$; *** $P \leq 0.001$; ** $P \leq 0.01$; * $P \leq 0.05$; ns, not significant.

Table 4. Effect of cultivar on appearance and colour changes of artichoke quarters stored at 5 °C and 20 °C

Parameter	C3	Catanese	Tema	Violetto Foggiano	Violetto Sardo
Δ*L*(%)					
5 °C	14.6^{a}	8.7^{c}	12.1^{ab}	11.5^{bc}	9.5^{bc}
20 °C	22.8^{a}	14.1^{c}	15.2^{bc}	17.7^{b}	17.6^{b}
Δ*a* (%)					
5 °C	−1163.9^{b}	−217.3^{a}	−181.7^{a}	−332.6^{a}	−222.4^{a}
20 °C	−1289.0b	−150.1^{a}	−136.1^{a}	−396.8^{a}	−243.0^{a}
Δ*b* (%)					
5 °C	8.1^{a}	−0.9^{ab}	−1.9^{ab}	−4.5^{c}	−0.2^{b}
20 °C	14.6^{a}	−5.6^{c}	−4.5^{bc}	−3.6^{bc}	−0.4^{b}
ΔHue (%)					
5 °C	19.1^{a}	11.2^{b}	12.5^{b}	12.9^{b}	12.7^{b}
20 °C	22.7^{a}	7.6^{c}	9.2^{c}	12.5^{b}	11.6^{b}
ΔChroma (%)					
5 °C	4.9^{a}	−2.3^{b}	−4.2^{bc}	−6.2^{c}	−2.1^{b}
20 °C	4.4^{a}	−6.6^{b}	−6.5^{b}	−7.8^{b}	0.9^{b}
Δ*E* (%)					
5 °C	10.9^{a}	6.5^{b}	8.1^{b}	8.2^{b}	7.0^{b}
20 °C	20.9^{a}	12.0^{d}	12.3^{cd}	15.6^{b}	14.9^{bc}
Score					
5 °C	2.9^{d}	3.4^{a}	3.2^{bc}	3.3^{ab}	3.1^{c}
20 °C	2.6^{c}	3.2^{a}	3.1^{ab}	3.1^{ab}	3.0^{b}
ΔFirmness (%)					
5 °C	16.1 ns	−8.7 ns	7.8 ns	27.6 ns	−10.1 ns
20 °C	18.2 ns	−36.4 ns	−31.6 ns	8.9 ns	−20.7 ns

Data indicate mean values during storage. Within the same row, values followed by the same letter are not significantly different, P ≤ 0.05. ns, not significant.

significant green component. This was also confirmed by the negative a^* value (−2.0) of C3, versus the slight positive value of Tema (0.2), and by its highest yellow index, b^* (28.8). C3 also showed the highest Chroma value (28.9). As for L^*, Catanese showed the highest value (79.9) while Tema showed the lowest (75.5).

Finally, firmness of artichoke bracts also showed significant differences among artichoke cultivars ranging from 55 N in Catanese to 72.7 N in C3.

Effect of cultivar and temperature on browning potential of fresh-cut artichokes during storage

Artichoke pieces underwent dramatic colour changes and browning processes that limited their storability to a few days depending on the storage temperature, higher temperatures fastened the browning process.

Table 3 reports the effect of the cultivar, time of storage, and cultivar × time interaction, on non-destructive parameters and firmness during storage at 5° and 20 °C. At 5 °C, the cultivar affected all parameters except firmness variation, while time of storage influenced all the parameters, apart from Δfirmness and Δa*. The cultivar × time interaction was significant only for Δb^*, Δhue and appearance score. At room temperature, all parameters were influenced by the cultivar, while time did not affect Δa^*, Δhue and Δfirmness; cultivar × time interaction was significant for Δb^* and appearance score.

The main effects of the cultivar on the tested attributes of fresh-cut artichokes stored at 5° and 20 °C for 7 days are reported in Table 4, as mean values throughout the storage period. There were noticeable colour changes for all cultivars thereby confirming the degradation of visual colour attributes of artichoke quarters. C3 was the cultivar with the highest colour variations both at 5° and at 20 °C, as shown by the highest ΔL^*, Δa^*, Δb^*, Δhue angle, and ΔE over time. Particularly, for this cultivar, Δa^* reached a negative variation of about −1200% at both temperatures (negative values indicate the increase of the parameter considered over time) versus a mean variation of about −200% for the other cultivars, reaching almost −400% for Violetto Foggiano stored at 20 °C. As for the ΔE value, which summarises colour variations, C3 showed the highest value among all cultivars both at 5° and at 20 °C (10.9 and 20.9, respectively). As for the remaining cultivars, no statistical differences were found at 5 °C, while at 20 °C, Catanese showed a ΔE value (12.0) statistically equal to Tema (12.3), but lower than Violetto sardo (14.9) and Violetto Foggiano (15.9), and C3. In general, artichoke quarters underwent colour changes during storage, from yellow green to dark brown, which explained the increase of a^* value (negative variation) and the decrease of Hue Angle and L^* value over time (positive variations). Figures 2 and 3 show the patterns of hue angle variation and appearance score throughout time, at both storage temperatures. It can be observed that after 2 days of storage, the hue angle extent of variation at

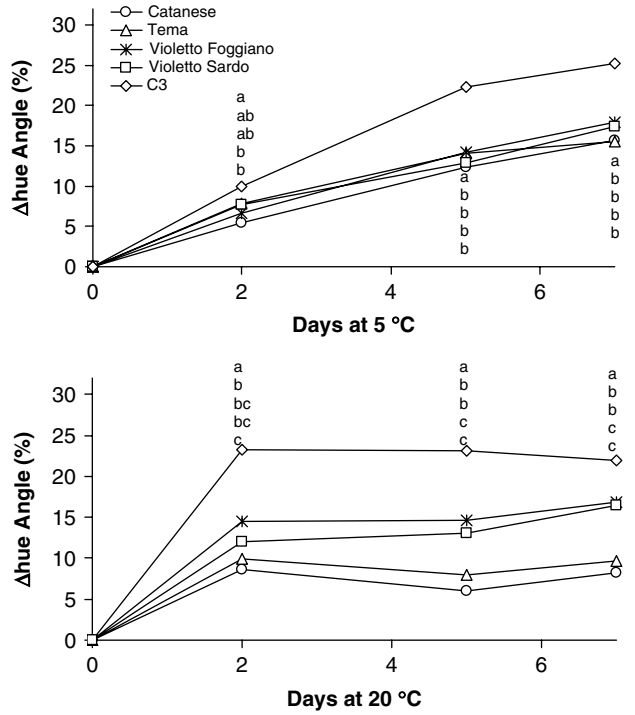


Figure 2. Effect of cultivar on colour change (Δhue angle) of artichoke quarters stored at 5 °C and at 20 °C for 7 days. Within the same storage evaluation, different letters indicate statistical differences, $P \leq 0.05$.

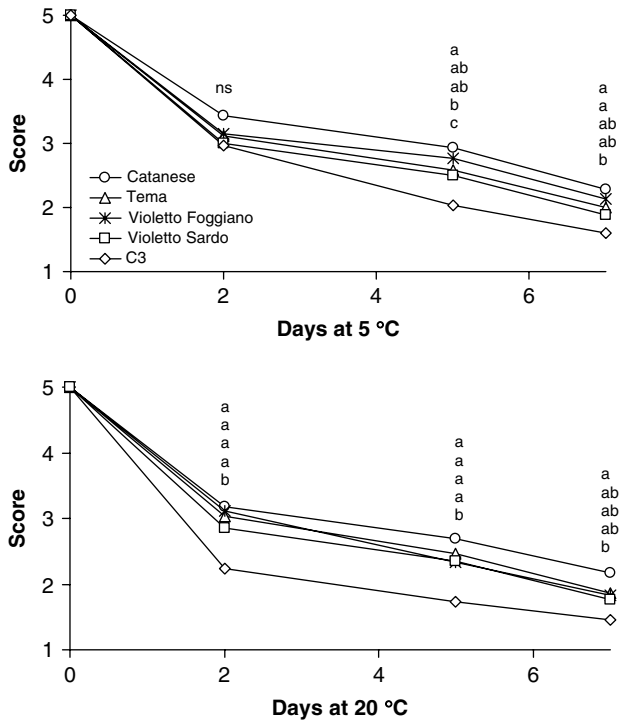


Figure 3. Effect of cultivar on general appearance (score) of artichoke quarters stored at 5 °C and at 20 °C for 7 days. Within the same storage evaluation, different letters indicate statistical differences, $P \leq 0.05$.

20 °C was much higher than that at 5 °C; however, at the end of storage, artichoke quarters stored at both temperatures reached almost the same value. C3 was significantly different from the other cultivars, and reached 24% of variation after 2 days of storage at 20 °C, versus 10% at 5 °C; after 7 days of storage about 25% of variation was observed at both temperatures. No differences among Δhue angles of the remaining cultivars were detected at 5 °C, reaching about 18% at the end of storage. At 20 °C, quarters of cultivars Catanese and Tema showed lower hue angle variation than Violetto Foggiano and Violetto Sardo.

As for appearance score, C3 showed the lowest values at both temperatures, and Catanese the highest, even though the latter was statistically different only from Violetto sardo after 5 days of storage at 5 °C, and from C3 (Fig. 3).

No statistical differences were found among tested cultivars for firmness changes although two different trends were observed: some cultivars showed negative variations, Catanese and Violetto Sardo at 5 °C, and Catanese, Tema and Violetto Sardo at 20 °C, while the others showed positive variations, where negative values implied an increase in cutting force over the experiment time (Table 4).

DISCUSSION

The artichoke cultivars tested showed a noticeable difference in quality at harvest and after minimally processing in terms of colour and appearance score. Catanese and Violetto Foggiano were characterised by the highest vitamin C content, and Tema by the lowest. The vitamin C content of Catanese and Violetto Foggiano were comparable to that reported by others, 193.5 mg kg^{-1} in the cv. Blanca de Tudela[15] and 108 mg kg^{-1} of edible fraction in an unknown cultivar,[24] while C3, Violetto Sardo and Tema exhibited a lower vitamin C content. No other publications were found comparing vitamin C in different artichoke cultivars, but a great variability may be expected, as reported for other species like potato,[25] sweet peppers,[26] and several brassica vegetables.[27] In the present work, vitamin C was mainly composed of DHA (an oxidative product of AA), which proved to be higher than the AA content for all cultivars. It is known that both forms have a biological activity; AA is the principal biologically active form although L-dehydroascorbic acid can be easily converted into AA in the human body.[28]

Phenol content also varied among tested cultivars with C3 artichokes showing the highest value (50% more than Catanese). Phenol content depends both qualitatively (type of phenols) and quantitatively (relative amounts of each phenol type) on the plant genetic information.[29] The highest phenol content of C3 was in accordance with that reported by Fratianni *et al.*,[8] comparing phenol content of five different Italian cultivars. Moreover, other authors reported different content in phenols and phenolic profiles among artichoke genotypes.[11,16] The high levels of phenolic compounds in artichokes could represent an important source of constituents with biological activity;[4] therefore, artichokes can be regarded as a functional food, as also concluded by Romani *et al.*[16] who found that heads of the cultivar Violetto di Toscana were very rich in phenolic compounds. Although some studies reported positive correlation between antioxidant activity and phenolics,[11,30] results of this work showed that the cultivar Tema, with a phenol content comparable to C3 showed a very low antioxidant activity, while at the other end the cultivar Catanese, with the lowest phenolic content, exhibited a relatively high antioxidant activity. This may be explained by a different phenolic profile,[3,31,32] leading to a different antioxidant activity, and by the contribution of the ascorbic acid.[33,34] Catanese was, in fact,

together with Violetto Foggiano, the cultivar with the highest vitamin C content. Antioxidant activity was also very high for cultivars Violetto Sardo and Violetto Foggiano. This may be due to their high phenol content and to their phenol composition which in Violetto cultivars, named after the violet hue of their colour, may include anthocyanin pigments with a strong antioxidant activity.[32]

The different composition and the extent of PPO activity may help explain the different suitability for minimally processing of the tested cultivars. Fresh-cut Catanese artichokes showed the best appearance and the longest shelf life, with Violetto Foggiano, Violetto Sardo, and Tema exhibiting an intermediate behaviour, and C3 statistically being the least adequate for fresh-cut preparation, due to an intense browning rate, as described by the lowest appearance score and the highest variation of colour attributes.

Phenol content may be directly correlated to the extent of browning in fresh-cut artichokes as found by Brecht *et al*.[10] The role of phenols in browning reactions catalysed by PPO enzymes in fruits and vegetables[35] is well known. Moreover, several studied on the browning process of artichoke heads have been conducted.[7,36,37] It has been reported that non-enzymatic reactions involving phenols, may also contribute to the browning of artichoke heads, specially in healthy tissues where the cell compartmentalisation is maintained, and phenols and PPO enzymes are located in separated cell structures. In that case, browning may be attributed to the interaction between phenols and iron, and to the consequent oxidation of iron ions. In mechanically damaged tissues, a greater impact of enzymatic browning is expected, as supported by a reduction in the phenol content, consequently to the formation of quinones catalysed by PPO enzymes.[7] Particularly, chlorogenic acid has been identified as the best substrate for artichoke PPO enzyme.[37] Results obtained in the present study for the cultivar C3, which showed an evident susceptibility to browning, were in accordance with this biochemical model, even though phenol content was not monitored during storage after cutting. Cultivar C3, which presented quite a high total phenol content and PPO activity, showed the worst appearance among the tested cultivars. Catanese, which showed the lowest phenol content, was the least susceptible to post-cutting browning, despite its high PPO activity. In addition to the low phenol content, the high DHA content, and DHA/vitamin C ratio observed for this cultivar may also explain its lower browning susceptibility. Ascorbic acid is a reducing agent that is involved in the prevention of melanin formation, due to its capability to reduce *o*-quinones to *o*-diphenol precursors,[15] being oxidised to DHA. The higher incidence of DHA versus AA found in the present study may, in fact, be explained by an intense oxidase activity of artichokes (ascorbate oxidase, polyphenol oxidase, cytochrome oxidase and peroxidase), as described by other authors in Swiss chard[38] and the artichoke cv. Blanca de Tudela.[15] Several studies reported the role of ascorbic acid in preventing browning as found for lettuce,[39] rocket leaves,[40] and some other vegetables.[31] Briefly, the high initial DHA content found in cultivar Catanese could be considered as a product of cell resistance to oxidation leading to a lower susceptibility to browning, also influenced by the lowest total phenol content among the cultivars tested. Tema, Violetto Foggiano and Violetto Sardo showed an intermediate sensitivity to browning, due to the intermediate level of phenols and PPO activity, with a slight lower appearance score for Violetto Sardo. Although the violet cultivars showed similar behaviour, they could not be discriminated from the white cultivars since their susceptibility to browning was in between that of two white cultivars (Catanese and C3). The anthocyanin fraction of phenol composition did therefore not directly affect the susceptibility to browning of artichoke cultivars, as much as the total phenol content and the extent of PPO activity characterising C3.

CONCLUSION

Different chemical compositions among cultivars lead to different nutritional quality of artichoke cultivars, which is an important attribute for fresh-cut produce. C3 was the greatest source of phenol bioactive compounds, but the least suitable to be processed as a fresh-cut produce, due to the direct role of phenols as substrate of browning reactions. The cultivar Catanese contained a significantly lower phenol content and was the most suitable cultivar for processing as a fresh-cut product. Despite its low phenol content, Catanese showed an antioxidant activity comparable to C3, probably due to its high vitamin C content; thus, its nutritional value was also very significant. Ascorbic acid may also have played an important role in browning resistance of fresh-cut Catanese artichokes. Results of this work contributed to increasing knowledge of the suitability of five artichoke cultivars, widely grown in Italy, to be processed as fresh cut, which represents the first key step in the implementation of the whole process. Further research may be aimed at evaluating the effect of additional technologies on delaying the browning process.

REFERENCES

1 Orlovskaya TV, Luneva IL and Chelombit'ko VA, Chemical composition of Cynara scolymus leaves. *Chem Nat Compd* **43**:239–240 (2007).
2 Lattanzio V, Kroonb PA, Linsalata V and Cardinali A, Globe artichoke: a functional food and source of nutraceutical ingredients. *J Functional Foods* DOI:10.1016/j.jff.2009.01.002.
3 Lattanzio V, Cicco N and Linsalata V, Antioxidant activities of artichoke phenolics. *Acta Hort* **681**:421–428 (2005).
4 Llorach R, Espin JC, Tomás-Barnerán FA and Ferreres F, Artichoke (*Cynara scolymus* L.) byproducts as a potential source of health-promoting antioxidant phenolics. *J Agric Food Chem* **50**:3458–3464 (2002).
5 Adzet T, Camarassa J and Laguna CJ, Hepatoprotective activity of polyphenolic compounds from *Cynara scolymus* against CCl_4 toxicity in isolated rat hepatocytes. *J Nat Prod* **50**:612–617 (1987).
6 Gebhardt R, Antioxidative and protective properties of extracts from leaves of the artichoke against hydroperoxide-induced oxidative stress in cultured rat hepatocytes. *Toxicol Appl Pharmacol* **144**:279–286 (1997).
7 Lattanzio V, Cardinali A, Di Venere D, Linsalata V and Palmieri S, Browning phenomena in stored artichoke (*Cynara scolymus* L.) heads: enzymic or chemical reaction? *Food Chem* **50**:1–7 (1994).
8 Fratianni F, Tucci M, De Palma M, Pepe R and Nazzaro F, Polyphenolic composition in different parts of some cultivars of globe artichoke (*Cynara cardunculus* L. *var. scolymus* (L.) Fiori). *Food Chem* **104**:1282–1286 (2007).
9 Tomás-Barberán FA and Espín JC, Phenolics compunds and related enzymes as determinants of quality in fruits and vegetables. *J Sci Food Agric* **81**:853–876 (2001).
10 Brecht JK, Saltveit ME, Talcott ST, Schneider KR, Felkey K and Bartz JA, Fresh-cut vegetables and fruits. *Hort Rev* **30**:185–250 (2004).
11 Wang M, Simon JE, Aviles IF, He K, Zheng Q and Tadmor Y. Analysis of antioxidative phenolic compounds in artichoke (*Cynara scolymus* L.). *J Agric Food Chem* **51**:601–608 (2003).
12 Gorny JR, Hess-Pierce B and Kader AA, Quality changes in fresh-cut peach and nectarine slices as effected by cultivar, storage atmosphere and chemical treatments. *J Food Sci* **64**:429–432 (1999).
13 Gorny JR, Cifuentes RA, Hess-Pierce B and Kader AA, Quality changes in fresh-cut pear slices as affected by cultivar, ripeness stage, fruit size, and storage regime. *J Food Sci* **65**:541–544 (2000).

14 Cantos E, Tudela JA, Gil MI and Espín JC, Phenolic compounds and related enzymes are not rate-limiting in browning development of fresh-cut potatoes. *J Agric Food Chem* **50**:3015–3023 (2002).
15 Gil-Izquierdo A, Gil MI, Conesa MA and Ferreres F, The effect of storage temperatures on vitamin C and phenolics content of artichoke (*Cynara scolymus* L.) heads. *Innov Food Sci Emerg Technol* **2**:199–202 (2001).
16 Romani A, Pinelli P, Cantini C, Cimato C and Heimler D. Characterization of Violetto di Toscana, a typical Italian variety of artichoke (*Cynara scolymus* L.). *Food Chem* **95**:221–225 (2006).
17 Alamanni MC and Cossu M, Antioxidant activity of the extracts of the edible part of artichoke (*Cynara scolymus* L.) var. spinoso sardo. *Ital J Food Sci* **15**:187–195 (2003).
18 Coinu R, Carta S, Urgeghe PP, Mulinacci N, Pinelli P, Franconi F, *et al*, Dose–effect study on the antioxidant properties of leaves and outer bracts of extracts obtained from Violetto di Toscana artichoke. *Food Chem* **101**:524–531 (2007).
19 Amodio ML, Cabezas-Serrano AB, Rinaldi R and Colelli G, Implementation of rating scales for visual quality evaluation of various vegetable crops, in *Produce Quality Rating Scales and Color Charts,* ed. by Kader AA and Cantwell M. *University of California Postharvest horticulture series* No. 23, Davis CA-USA, appendix 1 (2007).
20 Zapata S and Dufour JF, Ascorbic, dehydroascorbic and isoascorbic acid simultaneous determinations by reverse phase ion interaction HPLC. *J Food Sci* **57**:506–511 (1992).
21 Singleton VL and Rossi JA, Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *Am J Enol Vitic* **16**:144–158 (1965).
22 Brand-Williams W, Cuvelier ME and Berset C, Use of a free radical method to evaluate antioxidant activity. *Lebensm Wiss Technol* **28**:25–30 (1995).
23 Kahn V, Some biochemical properties of phenol oxidase from two avocado varieties differing in their browning rates. *J Food Sci* **42**:38–43 (1977).
24 Ihl M, Monsalves M and Bifani V, Chlorophyllase inactivation as a measure of blanching efficacy and colour retention of artichokes (*Cynara scolymus* L.). *Lebensm Wiss Technol*, **31**:50–56 (1998).
25 Tudela JA, Espín JC and Gil MI, Vitamin C retention in fresh-cut potatoes. *Postharvest Biol Technol* **26**:75–84 (2002).
26 Deepa N, Charanjit K, Balraj S and Kapoor HC, Antioxidant activity in some red sweet pepper cultivars. *J Food Compos Anal* **19**:572–578 (2006).
27 Singh J, Upadhyay AK, Prasad K, Bahadur A and Rai M, Variability of carotenes, vitamin C, E and phenolics in Brassica vegetables. *J Food Compos Anal* **20**:106–112 (2007).
28 Lee K and Kader A, Preharvest and postharvest factors influencing vitamin C content of horticultural crops. *Postharvest Biol Technol* **20**:207–220 (2000).
29 Shahidi F and Naczk M, Antioxidant properties of food phenolics, in *Food Phenolics: Sources, Chemistry, Effects and Applications*, ed. by Shahidi F and Naczk M. Technomic Publishing Co., Lancaster, PA, pp. 235–277 (1995).
30 Ferracane R, Pellegrini N, Visconti A, Graziani G, Chiavaro E, Miglio C, *et al*, Effects of different cooking methods on antioxidant profile, antioxidant capacity, and physical characteristics of artichoke. *J Agric Food Chem* **56**:8601–8608 (2008).
31 Reyes LF, Villareal JE and Cisneros-Zevallos L, The increase in antioxidant capacity after wounding depends on the type of fruit or vegetable tissues. *Food Chem* **101**:1254–1262 (2007).
32 Rice-Evans CA, Miller NJ and Paganga G, Antioxidant properties of phenolic compounds. *Trends Plant Sci* **2**:152–159 (1997).
33 Cocci E, Rocculi E, Romani S and Dalla Rosa M, Changes in nutritional properties of minimally processed apples during storage. *Postharvest Biol Technol* **39**:265–271 (2006).
34 Ferreyra RM, Vina SZ, Mugridge A and Chaves AR, Growth and ripening season effects on antioxidant capacity of strawberry cultivar Selva. *Sci Hort* **112**:27–32 (2007).
35 Vamos-Vigyazo L, Polyphenoloxidase and peroxidase in fruits and vegetables. *CRC Crit Rev Food Sci Nutr* **15**:49–127 (1981).
36 Lattanzio V, Linsalata V, Palmieri S and Van Sumere CF, The beneficial effect of citric and ascorbic acid on phenolics browning reaction in stored artichoke (*Cynara scolymus* L.) heads. *Food Chem* **33**:93–106 (1989).
37 Leoni O, Palmieri S, Lattanzio V and Van Sumere CF, Polyphenol oxidase from artichoke (*Cynara scolymus* L.). *Food Chem* **38**:27–39 (1990).
38 Gil MI, Ferreres F and Tomás-Barberán FA. Effect of modified atmosphere packaging on the flavonoids and vitamin C content of minimally processed Swiss chard. *J Agric Food Chem* **46**:2007–2012 (1998).
39 Heimdal H, Kuhn BF, Poll L and Larsen LM, Biochemical changes and sensory quality of shredded and MA-package iceberg lettuce. *J Food Sci* **60**:1265–1268 (1995).
40 Degl'Innocenti E, Pardossi A, Tognoni F and Guidi L, Physiological basis of sensitivity to enzymatic browning in 'lettuce', 'escarole' and 'rocket salad' when stored as fresh-cut products. *Food Chem* **104**:209–215 (2007).

Capítulo 5

Capítulo 5. SELECCIÓN Y EVALUACIÓN DE DISTINTOS TRATAMIENTOS ANTIOXIDANTES PARA EL MANTENIMIENTO DE LA CALIDAD EN PATATAS Y ALCACHOFAS DE IV GAMA

5.1. RESPONSE OF FRESH-CUT POTATO CUBES OF THREE DIFFERENT VARIETIES TO ANTI-BROWNING TREATMENTS. ACTA HORTICULTURE 876, 319-324 (2010)

Response of Fresh-Cut Potato Cubes of Three Different Varieties to Anti-Browning Treatments

R. Rinaldi, A.B. Cabezas-Serrano, R. Cornacchia, M.L. Amodio and G. Colelli
Dip.to di Scienze delle Produzioni e dell'Innovazione nei Sistemi
Agro-Alimentari Mediterranei, Università di Foggia, Via Napoli 25
71100 Foggia
Italy

Keywords: convenience food, antioxidant, browning, quality, pre-treatments, shelf-life

Abstract

Fresh-cut potatoes present many problems related to a very high potential for browning of cut surfaces. In a previous survey on 9 potato cultivars, 'Marabel', 'Agata' and 'Safrane', resulted the least susceptible to post-cutting browning. In the present work, these varieties were tested with the following pre-treatments, found in the recent literature as successfully in controlling browning: (i) AA+Cys, dip in a 2% of citric acid and 0.5% of cysteine solution for 3 min; (ii) AA+CA, dip in 0.1% ascorbic acid + 0.5% citric acid solution for 1 minute; (iii) AA+CA+$CaCl_2$, dip in 0.3% ascorbic acid + 0.3% citric acid + 0.1% calcium chloride solution for 1 min; (iv) AA+CA+KSorb, dip in 0.5% ascorbic acid + 0.5% citric acid + 0.2% potassium sorbate solution for 1 min; (v) AA+CA+NaPP, dip in 4% ascorbic acid + 1% citric acid + 1% sodium pirophosfate acid for 5 mins; (vi) COMB 50°C, dip in 1% ascorbic acid + 2% citric acid solution at 50°C for 5 min followed by a dip in 4% ascorbic acid + 1% citric acid + 1% sodium pirofosfate acid solution for 5 min. These treatments were compared either with a dip in distilled water (CTRL) and with a dip in 1% potassium metabisulfite solution for 1 min ($K_2S_2O_5$). Potato cubes were then stored at 5°C and evaluated for overall appearance, colour, and firmness during storage. Treatments COMB 50°C and $K_2S_2O_5$ allowed to maintain an overall score still above the limit of marketability after 16 days of storage for 'Marabel' cubes, while for 'Safrane' COMB 50°C was more effective than $K_2S_2O_5$. For 'Agata', AA+CA+NaPP and $K_2S_2O_5$ treatments had the most effective anti-browning action in terms of highest appearance score, while AA+CA+NAPP induced lower firmness loss, compared to $K_2S_2O_5$.

INTRODUCTION

Genotype is one of the most important pre-harvest factors to influence postharvest performances of vegetables (Kim et al., 1993; Roming, 1995). Fresh-cut potatoes present particular process challenges because of their susceptibility to browning of cut surfaces. Cabezas et al. (2009) comparing the post-cutting performance of 5 winter potato varieties, reported significant differences in terms of composition and browning susceptibility among varieties and found 'Marabel' and 'Agata' the most suitable varieties to be processed as a fresh-cut product. In another study 'Safrane' showed similar post-cutting performances among 4 summer varieties (unpublished data). The general approach beyond the cultivar selection is to use anti-browning compounds, as post-cutting treatment.

There are many substances which inhibit directly or indirectly the action of enzymes responsible for oxidation of the tissues in the vegetal products, as ascorbic acid, (Whitacker, 1994), L-cysteine (Gunes and Lee, 1997), sodium chloride (Rouet-Mayer and Philippon, 1986), and calcium compounds (Drake and Spayd, 1983). In particular on potatoes several pre-treatment studies have been published reporting the use of sulphur dioxide and of other substances (Giannuzzi and Zaritzky, 1991; Sapers and Miller, 1995; Gomez-Gimenez, 1997; Buta and Moline, 2001) including antibrowning cocktails like 2% citric acid + 0.5% cysteine (Gunes and Lee, 1997), 0.1% ascorbic acid + 0.5% citric acid (Laurilia et al., 1998), 0.3% ascorbic acid + 0.3% citric acid + 0.1% calcium chloride

(Mattila et al., 1993), 0.5% ascorbic acid + 0.2% potassium sorbate + 0.5% citric acid (Mattila et al., 1993); 4% ascorbic acid + 1% citric acid + 1% of sodium pirofosfate acid (Sapers and Miller, 1995), blanching in a 1% ascorbic acid + 2% citric acid solution at 50°C for 5 min followed by immersion for 5 min in a 4% ascorbic acid + 1% citric acid + 1% sodium pirofosfate acid solution (Sapers and Miller, 1995). The objective of this paper was to compare the effect of the cited pre-treatments on fresh-cut potatoes of 3 different varieties which in previous studies proved to be less susceptible to post-cutting browning compared to other winter and summer varieties.

MATERIALS AND METHODS

Three experiments were carried out, one for each variety ('Marabel', 'Agata' and 'Safrane') testing the effect of the following anti-browning treatments:

– AA+Cys: immersion in a 2% of citric acid and 0.5% of cysteine solution for 3 min;
– AA+CA: immersion in a 0.1 of ascorbic acid and 0.5% citric acid solution for 1 min;
– AA+CA+$CACl_2$: immersion in a 0.3% of ascorbic acid, 0.3% of citric acid and 0.1% of sodium chloride solution;
– AA+CA+KSorb: immersion in a 0.5% of ascorbic acid, 0.2% of potassium sorbate, and 0.5% of citric acid solution for 1 min;
– AA+CA+NaPP: immersion in a 4% of ascorbic acid, 1% of citric acid, 1% of sodium pirofosfate acid for 5 min;
– COMB 50°C: immersion in a 1% of ascorbic acid 2% of citric acid solution for 5 min at 50°C followed from one immersion for 5 min in a 4% of ascorbic acid, 1% of citric acid, 1% of sodium pirofosfate acid solution;
– $K_2S_2O_5$: immersion in 1% potassium metabisulfite for 1 min;
– CTRL: water immersion for 1 min.

Each treatment was replicated three times on 10 cubes. Color, general appearance and firmness were monitored after 0, 3, 8, 13, and 16 days of storage for 'Marabel' (except for firmness that was not measured at 13 days), after 0, 3, 8, and 13 days for 'Agata', and after 0, 1, 2, 3, 6, and 8 days for 'Safrane'.

Color was measured using a Minolta colorimeter, appearance score was attributed on each cube by a semi-trained panel using a subjective scale from 5 to 1, where 5=excellent, no defects, 4=very good, minor defects, 3=fair, moderate defects, 2=poor, major defects, 1=inedible. A score of 3 was considered as the limit of marketability (Amodio et al., 2007). Firmness was measured with and Instron machine, as the maximum load necessary for the rupture of the cubes.

A multifactor ANOVA organized in a split plot design with treatment as main plot and storage time as subplot was performed on data means. For each storage duration, the effect of each treatment was evaluated with a one-way ANOVA and means separation was assessed with the Tukey test.

RESULTS AND DISCUSSION

Statistical results indicated a significant effect of treatment and time of storage for each evaluated quality attribute. In addition, strong interaction treatment×time was found (data not shown). In Figures 1, 2 and 3 the effect of treatment on quality attributes of potato cubes during storage is shown, respectively for 'Marabel', 'Agata' and 'Safrane'.

As for 'Marabel' (Fig. 1) it can be observed that the treatment COMB 50°C induced from the first evaluation time, a slower reduction of acceptability in terms of general appearance, compared to the other treatments. However, at the end of storage only COMB 50°C and $K_2S_2O_5$ could be distinguished from the other treatments, showing a sensible difference on final score values. In fact, while all treatments received an appearance score lower than 2, cubes treated with COMB 50°C and with $K_2S_2O_5$ after 16 days of storage were still over the limit of marketability. Cubes treated with $K_2S_2O_5$ showed a noticeable lowest increase of a* value, statistically lower than all other treatments, including COMB 50°C which resulted the second lowest a* value. This difference was also important because a* values started from a negative value of about -6

and reached positive values in all treatments, except for $K_2S_2O_5$, which at the end of the storage, reached a value of about -3. The positive a* values indicated an increase of the red component, that in AA+CA treated cubes reached the highest value. This treatment in fact presented also the highest Hue Angle variation (about 30% of the initial 100°), moving from the green-yellow region on the second quarter of the CIE L*a*b* color scale to the yellow-red region on the first quarter. No significant differences in terms of Hue Angle variations were observed between $K_2S_2O_5$ and COMB 50°C treated cubes. The fact that color variation did not affect sensorial evaluation of the cubes may be explained by the fact that values of ΔE of $K_2S_2O_5$ and COMB 50°C treated cubes at each storage evaluation were very similar (data not shown). In fact to be perceivable by the human eye, a difference in color needs to have a difference in ΔE values of at least 4 (CIE, 2004). For firmness different trends were observed among treatments. COMB 50°C and $K_2S_2O_5$ treatments induced a significant firmness reduction of 11 and 27% respectively, but statistically comparable. AA+CA, AA+CA+$CACl_2$ and AA+NaSorb induced a firmness increase that reached up the 23%, while for all the other treatments, firmness remained almost constant.

Results on 'Agata' cubes showed smaller differences among treatments for appearance score (Fig. 2). Potato treated with CA+Cys showed the lowest score values after 3 days of storage, while starting from day 8, AA+CA+KSorb treated cubes received the lowest values. At 13 days of storage, AA+CA+NaPP and COMB 50°C received a score significantly higher than AA+Cys, and just below the limit of marketability, suggesting a potential shelf-life from 8 to 12 days. In this case, $K_2S_2O_5$ treatment induced an abnormal surface whitening, as evidenced by the L* increase (data not shown) and had performance comparable to control treated cubes. Cubes treated with AA+Cys showed the highest color changes (as mean value) in terms of a* increase and Hue Angle reduction, even if not always significantly different from the other treatments. As for 'Marabel', 'Agata' potatoes treated with $K_2S_2O_5$ showed a final a* value more similar to the initial value, than the other treatments, remaining in the negative part of the graph. Variation in Hue Angle showed for this treatment a slight reduction over time with values significantly higher than the other treatments until day 8, and becoming more similar to AA+CA+Ksorb, AA+CA+NaPP and control treated cubes at the end of the storage, but remaining higher than 90°, unlike all the other treatments. For this variety the firmness reduction for $K_2S_2O_5$-treated cubes was much higher than that observed for COMB 50°C-treated cubes, which remained almost constant throughout the storage time. A slight firmness increase was observed for CA+Cys, AA+CA+$CaCl_2$ and control treated cubes.

Finally, results on 'Safrane' (Fig. 3) showed a good performance of the combined treatment at 50°C (COMB 50°C). In fact, cubes treated with COMB 50°C, after 8 days of storage received an appearance score higher than that received by $K_2S_2O_5$-treated cubes. For this variety, control cubes received the lowest score, which after 8 days at 5°C reached a value near to 1 (limit of edibility), indicating a higher browning susceptibility of this variety when compared to the untreated 'Marabel' and 'Agata' cubes. Moreover, after 8 days of storage all treatments received a score lower than 3, indicating a shelf-life of about 6 days only when treated with COMB 50°C or $K_2S_2O_5$. As for color changes, at the end of the storage, cubes treated with $K_2S_2O_5$ confirmed what had already been observed for 'Marabel' and 'Agata' in terms of increase of a* into positive values, while Hue Angle resulted significantly higher than control cubes in the last part of the experiment. Changes in other color parameters did not give a clear indication, except for the lower Chroma value observed in control cubes at the end of storage.

Results obtained in these trials confirmed that the optimal anti-browning treatments of fresh-cut potatoes may vary in relation to the cultivar (Mattila et al., 1993). Difference of post-cutting performance among potato varieties was also proved by the different shelf-life of untreated cubes; untreated winter varieties had a shelf-life of 8 and 13 days for 'Marabel' and 'Agata' respectively, while untreated 'Safrane' cubes were already not marketable after 3 days of storage.

The use of COMB 50°C treatment, as reported by Sapers and Miller (1995) was found to have a comparable effect of the treatment with $K_2S_2O_5$ on the appearance score of 'Marabel', and even a better performance on 'Safrane' after 8 days in storage. For 'Agata', AA+CA+NaPP treated cubes at room temperature and COMB 50°C dipping resulted in the best performance in term of color changes and appearance score.

CONCLUSIONS

Fresh-cut potato is a basic ingredient for a ready-to-use vegetable mix which is having increasing success on the market. Given its high susceptibility to browning it is very important to find a feasible anti-browning treatment alternative to sulphites, which so far have been diffusely used on this commodity, which would ensure a quality life comparable to the other components of the mix. Although it would be highly desirable to select a good-for-all anti-browning treatment, according to the results obtained in this study, cultivars may respond differently to the same treatment, and it might be useful to customize the post-cutting procedure according to their response. On the other hand some additional work might help to better understand causes which determine different responses and optimize anti-browning procedures.

Literature Cited

Amodio, M.L., Cabezas-Serrano, A.B., Rinaldi, R. and Colelli, G. 2007. Implementation of rating scales for visual quality evaluation of various vegetable crops. In: A.A. Kader and M. Cantwell (eds.), Produce Quality Rating Scales and Color Charts., Postharvest horticulture series NO. 23, University of California, Davis, CA-USA.

Buta, J.G. and Moline, H.E. 2001. Prevention of browning of potato slices using polyphenoloxidase inhibitors and organic acids. J. Food Qual. 24(4):271-282.

Cabezas, A.B., Amodio, M.L., Cornacchia, R., Rinaldi, R. and Colelli, G. 2009. Suitability of five different potato cultivars (*Solanum tuberosum* L.) to be processed as fresh-cut products. Postharvest Biol. Technol., doi:10.1016/j.postharvbio.2009.03.009.

Drake, S.R. and Spayd, S.E. 1983. Influence of calcium treatment on 'Golden delicious' apple quality. J. Food Sci. 48:403-405.

Giannuzzi, L. and Zaritzky, N.E. 1991. The effect of packaging film on the shelf-life of treated refrigerated pre-peeled potatoes. Packaging Technol. Sci. 4(2):69-76.

CIE. 2004. Colorimetry, CIE Pb. 15:2004, Central Bureau of the CIE, Vienna, p.20-21.

Gomez-Gimenez, V.L. 1997. Process for the conservation of peeled fresh potatoes. PCT-International Patent Application.

Gunes, G. and Lee, C.Y. 1997. Colour of minimally processed potatoes as affected by modified atmosphere packaging and antibrowning agents. J. Food Sci. 62:572-575, 582.

Kim, D.M., Smith, N.L. and Lee, C.Y. 1993. Apple cultivar variations in response to heat treatment and minimal processing. J. Food Sci. 58:1111-1114, 1124.

Laurilia, E., Hurme, E. and Ahvenainen, R. 1998. Shelf life of sliced raw potatoes of various cultivar varieties - substitution of bisulfites. J. Food Protection 61:1363-1371.

Mattila, M., Ahvenainen, R. and Hurme, E. 1993. Prevention of browning of pre-peeled potato. In: J. De Baerdemaker et al. (eds.), COST 94, Proc. Workshop "Systems and operations for post-harvest quality". Leuven, Belgium.

Roming, W.R. 1995. Selection of cultivar for lightly processed fruits and vegetables. HortScience 30:38-40.

Rouet-Mayer, M.A. and Philippon, J. 1986. Inhibition of catechol oxidases from apples by sodium chloride. Phytochemistry 25:2717-2719.

Saper, G.M. and Miller, R.L. 1995. Heated ascorbic/citric acid solution as browning inhibitor for pre-peeled potatoes. J. Food Sci. 60:762-766.

Whitaker, J.R. 1994. Priciples of enzymology for the food sciences. New York, Marcel Dekker, 2nd ed.

Figures

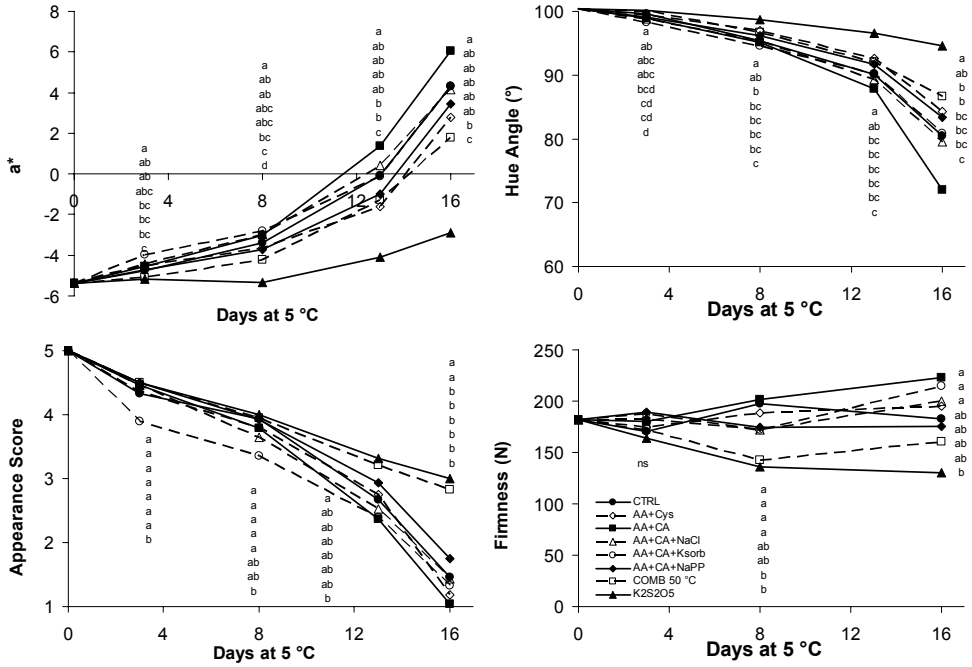


Fig. 1. Effects of anti-browning treatments on color parameters (a* and Hue Angle), general appearance score and firmness of 'Marabel' potato cubes stored at 5°C. For each storage duration different letters indicate significant differences according to Tukey test for P=0.05; ns indicates difference is not statistically significant.

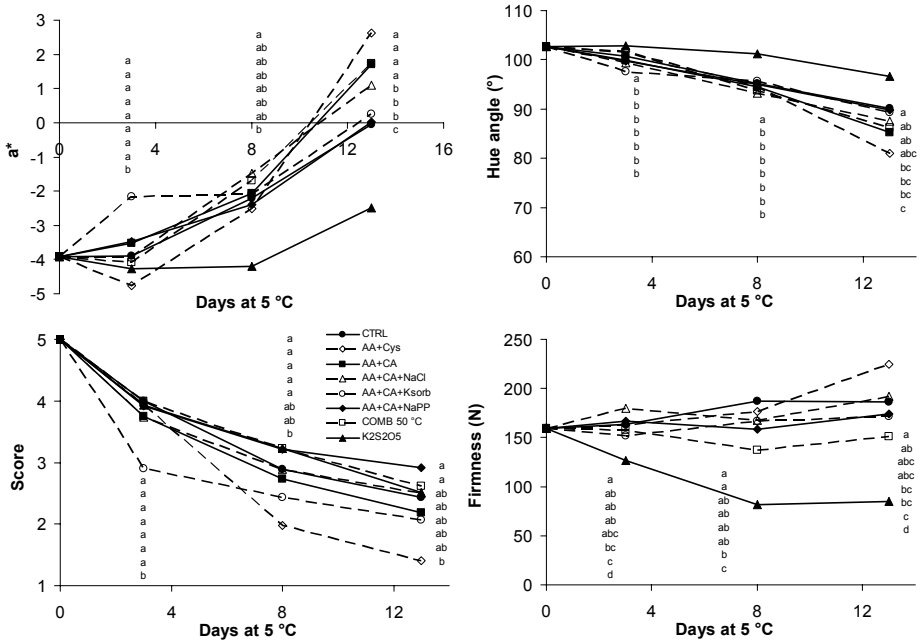


Fig. 2. Effects of anti-browning treatment on color parameters (a* and Hue Angle), general appearance score, and firmness of 'Agata' potato cubes stored at 5°C. For each storage duration different letters indicate significant differences according to Tukey test for P=0.05; ns indicates difference is not statistically significant.

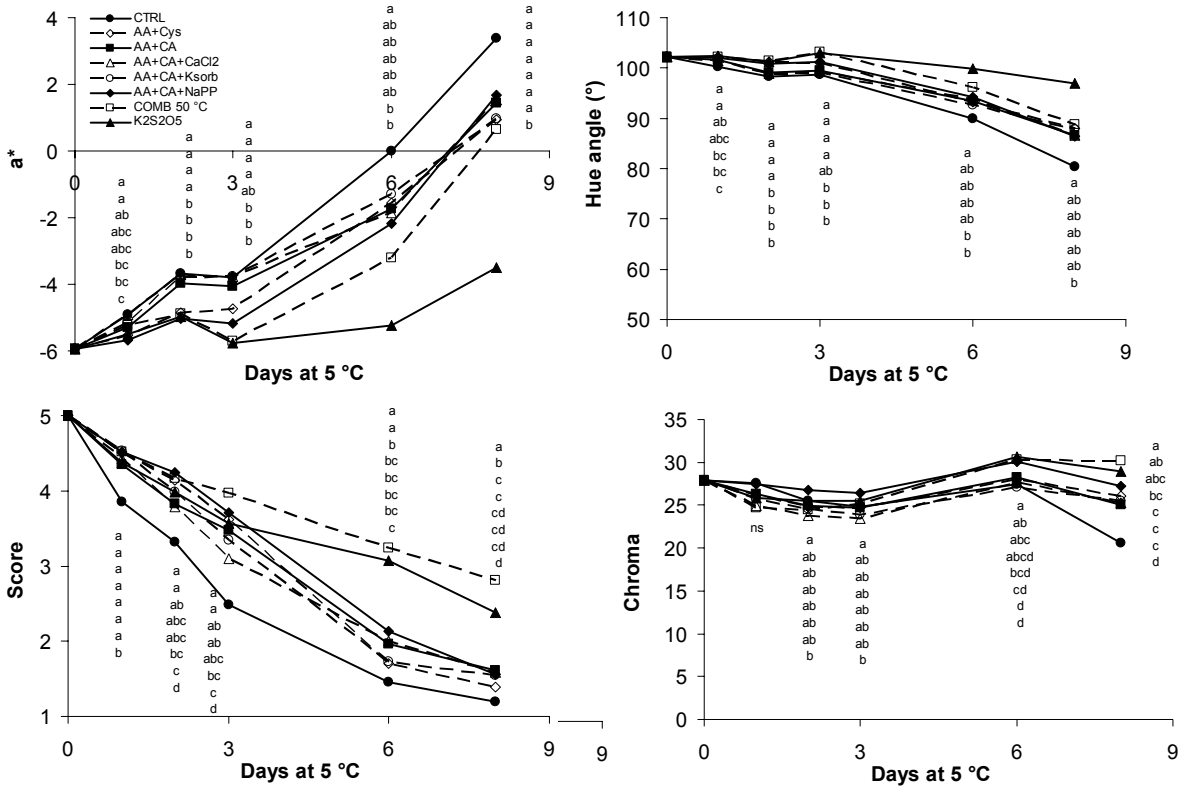


Fig. 3. Effects of anti-browning treatment on color parameters (a*, Hue Angle, and Chroma), and general appearance score of 'Safrane' potato cubes stored at 5°C. For each storage duration different letters indicate significant differences according to Tukey test for P=0.05; ns indicates difference is not statistically significant.

5.2. POST-CUTTING QUALITY CHANGES OF FRESH-CUT ARTICHOKES TREATED WITH DIFFERENT ANTI-BROWNING AGENTS AS EVALUATED BY IMAGE ANALYSIS. POSTHARVEST BIOLOGY AND TECHNOLOGY 62, 213-220 (2011)

Postharvest Biology and Technology 62 (2011) 213–220

Contents lists available at ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Post-cutting quality changes of fresh-cut artichokes treated with different anti-browning agents as evaluated by image analysis

M.L. Amodio*, A.B. Cabezas-Serrano[1], G. Peri, G. Colelli

Dip.to PRIME, Università degli Studi di Foggia, Via Napoli 25, 71122 Foggia, Italy

ARTICLE INFO

Article history:
Received 23 February 2011
Accepted 14 May 2011

Keywords:
Cynara scolimus L.
Appearance
Cysteine
Browning
Computer vision system
Dipping

ABSTRACT

Fresh-cut processing can add convenience to artichoke consumption, although post-cutting browning is still a major problem. Different compounds (ascorbic acid, citric acid, cysteine, and their combination, ethanol, sodium chloride, 4-hexylresorcinol) were tested at different concentrations in two experiments. An algorithm for rapid colour measurements by means of image analysis was implemented, and allowed measurement of L*, a*, and b* values from the whole quarter surface and from the browned areas, while the external appearance of artichoke quarters was evaluated using an anchored subjective scale. Cysteine (0.5%) was the most effective treatment to prevent browning as evaluated by colour attributes and appearance score. Its effectiveness was improved by increasing the pH of the solution from the natural pH (2.1) to pH 3, resulting in L* values of browned areas about 30% higher than controls (27.4 and 21.5 respectively). The mean values of appearance scores for cysteine treated samples were all above the limit of marketability (score 3), significantly higher than in control samples which had mean values below this limit. All colour parameters were significantly correlated with appearance scores, and L* of the whole quarter surface had the highest correlation. The results represent a step forward in research on anti-browning treatments for fresh-cut artichokes, also providing an objective tool for colour evaluation.

1. Introduction

Processing artichokes as fresh-cut would provide convenience due to the high percentage of discarded plant waste, and the complexity of preparation and trimming operations. The main problem with fresh-cut artichokes is the high browning rate of the cut surfaces (receptacle and bracts) caused by oxidation of phenolics catalysed by polyphenol oxidase (PPO) enzymes, with subsequent formation of dark compounds (Lattanzio et al., 1994; Tomás-Barberán and Espín, 2001; Cabezas-Serrano et al., 2009). Most studies on minimally processed artichokes (trimmed and washed) concern the use of modified atmospheres and innovative packaging (Giménez et al., 2003; Del Nobile et al., 2009), but none has aimed at finding effective anti-browning treatments. Browning may be prevented by inhibiting the activity of PPO by removing one of its necessary reaction components, O_2, enzyme, Cu^{2+} contained on its active site, or substrate (Richardson and Hyslop, 1985; Lambrecht, 1995), or by mechanical or chemical methods (Garcia and Barrett, 2002). Chemical methods consist of using different types of additives as reducing, acidulant, chelating, and complexing agents, or compounds that directly inhibit PPO (Ahvenainen, 1996; Garcia and Barrett, 2002). Ascorbic and citric acids have been shown to be effective anti-browning agents on different fresh-cut products such as apples (Tortoe et al., 2007), pears (Gorny et al., 2000), and artichoke heads (Lattanzio et al., 1989). Among agents acting as competitive inhibitors of PPO, L-cysteine and 4-hexylresorcinol have been effective in preventing colour changes in mango puree (Guerrero-Beltrán et al., 2005). Exposing leaf tissue to vapours or aqueous solutions of n-alcohols inhibited wound-induced tissue browning in lettuce (Choi et al., 2005). Janovitz-Klapp et al. (1990) found that sodium chloride inhibited apple PPO. Given these results on fresh-cut produce, it was of interest to test the efficacy of these anti-browning compounds on fresh-cut artichokes.

One additional problem in working towards a strategy for delaying browning of cut artichokes is the difficulty of using conventional colorimetric instruments to measure colour. These instruments may be used to measure colour and, therefore, the extent of browning (Rico et al., 2007), but can operate only on flat surfaces, and on limited observation points, that for cut artichokes normally are the receptacle (Melilli et al., 2004; Cabezas-Serrano et al., 2009), or the outer surface of the bracts (Raccuia and Melilli, 2004). This means that they provide a measure which is not representative of the whole product if the colour is not uniform. Therefore, in order to have an indication of the overall colour surface and the

* Corresponding author. Tel.: +39 0881589105; fax: +39 0881589244.
E-mail address: m.amodio@unifg.it (M.L. Amodio).
[1] Present address: Departamento de Bromatología y Tecnología de los Alimentos. Universidad de Córdoba, 14001 Cordoba, Spain.

0925-5214/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.postharvbio.2011.05.004

extent of browning of fresh-cut products, sensory rating scales are often used, as reported for bananas (Moline et al., 1999), apples (Tortoe et al., 2007), peaches (Amodio and Colelli, 2008), and several vegetables (Amodio et al., 2006), including a study on fresh-cut artichokes which aimed to choose the most suitable cultivar for fresh-cut processing (Cabezas-Serrano et al., 2009).

Colour can be objectively and rapidly measured by computerized image analysis techniques, also known as computer vision systems. These systems not only offer a methodology for the measurement of uneven colour surfaces but can also be applied to the measurement of other attributes of overall appearance (Hutchings, 1999). The advantages of a computer vision system over traditional techniques (colorimeters and spectrophotometers) have been shown in many studies (O'Sullivan et al., 2003; Brosnan and Sun, 2004; Chen et al., 2010).

Basically, the system consists of a digital photo or video camera for image acquisition, a light source, and an image processing software (Papadakis et al., 2000; Brosnan and Sun, 2004). Starting from the RGB image, the software can convert the original image to other colour spaces such as L*a*b* (Leon et al., 2006) or HSV (Peri et al., 2005), that are normally used as colour references in food research. The more critical step in this image processing is to isolate the region of interest (that can be the whole object or part of it) within the image, and this is done by image segmentation (Gunasekaran, 1996). Image segmentation and colour measurements may be performed by means of an algorithm, as reported in the literature for several applications such as evaluation of colour and browning incidence of basil leaves (Peri et al., 2005), and muscle colour and marbling features on beef (Jackman et al., 2009; Chen et al., 2010). No applications are currently available for fresh-cut artichokes, and this may be the factor limiting the research on anti-browning treatments for this product, compared to many others (Monsalve-Gonzalez et al., 1995; Buta and Abbott, 2000; González-Aguilar et al., 2001).

The objectives of this work were: (i) to delay post-cutting browning of fresh-cut artichokes, comparing the effectiveness of a number of anti-browning agents, and (ii) to implement an algorithm for colour measurements of fresh-cut artichokes using image analysis to support decisions on the efficacy of anti-browning compounds, at present mainly carried out on the basis of sensory evaluations.

2. Materials and methods

2.1. Plant material and experiment design

Artichokes (*Cynara scolymus* L. cv. Catanese) from the Brindisi area (Southern Italy) were harvested when they reached commercial maturity (defined by the compactness of fully developed buds), and were directly transported to the postharvest laboratory at the University of Foggia. 'Catanese' is a white variety, that in a previous study was found as the most suitable for fresh-cut processing among 5 artichoke varieties (Cabezas-Serrano et al., 2009). Two experiments were consecutively conducted, using plant material from the same farm.

Artichokes were processed on the same day in a cold room at 10 °C under suitable hygienic conditions. Heads were hand-trimmed using sharp stainless steel knives in order to remove external bracts, leaves and stalks and then washed in a NaOCl solution (0.01%, w/w of free chlorine at about a room temperature of 10 °C) to eliminate soil and insect residues. After washing, head trimming was completed by further removal of external greener and tougher bracts (inedible fraction) so as to retain just the innermost tender bracts. Artichoke hearts were then cut into quarters. Batches of 48 quarters were dipped in water as an untreated control or with an anti-browning solution at room temperature for 1 min, as reported in Table 1. Anti-browning agents were chosen among the most effective in preventing browning of several fresh-cut products, as reported in the literature. Each dipping was replicated three times. A second experiment aimed to test the effect of higher concentrations of the most effective compounds, and of some of their combinations. Artichokes were processed as in the first experiment and subjected to the treatments reported in Table 1.

Table 1
Active compounds, concentrations and abbreviations used for the dippings applied to fresh-cut artichokes in the two experiments.

Experiment	Active compound	Concentration (w/w)	Abbreviation
1	Water	CTRL	
1	Sodium chloride	0.5%	0.5% NaCl
1	Sodium chloride	1%	1% NaCl
1	Citric acid	0.5%	0.5% CA
1	Citric acid	1%	1% CA
1	Ascorbic acid	0.5%	0.5% AA
1	Ascorbic acid	1%	1% AA
1	Ethanol	0.5%	0.5% EtOh
1	Ethanol	1%	1% EtOh
1	Cysteine	0.25%	0.25% CYS
1	Cysteine	0.5%	0.5% CYS
1	4-Hexylresorcinol	0.01%	0.01% 4HR
2	Water	CTRL	
2	Citric acid	1%	1% CA
2	Citric acid	2%	2% CA
2	Ascorbic acid	1%	1% AA
2	Ascorbic acid	2%	2% AA
2	Cysteine	0.5%	0.5% CYS
2	Cysteine pH3	0.5%	0.5% CYS pH 3
2	Cysteine	1%	1% CYS
2	Ascorbic acid + citric acid + cysteine	1% + 1% + 0.5%	CA + AA + CYS

After each dipping, the quarters of each replicate were gently dried by hand using cheesecloth, divided into 4 lots of 12 pieces (one for each storage duration) and put into plastic trays. The trays were then placed in plastic jars and connected to a continuous humidified air flow in a room at 5 °C.

At day 0 upon cutting (for untreated samples), and at 3, 24, 48, and 120 h of storage in humidified air at 5 °C after the dipping, samples were evaluated for appearance score and rapidly submitted to image acquisition.

2.2. Appearance score evaluation

Appearance score evaluation was subjectively assessed by a group of 3 blind laboratory panellists, using as a reference a photographic scale associated with brief descriptions, in which: 5 = excellent; 4 = good; 3 = fair (limit of marketability); 2 = poor (limit of edibility); 1 = very bad, unedible (Amodio et al., 2007), which was also used for the training of the judges. A score of 3 was considered as the limit of marketability and a score of 2 as the limit of edibility (Amodio et al., 2007; Cabezas-Serrano et al., 2009).

2.3. Image analysis

The digital colour camera (Canon EOS 400D, USA) was located vertically over a matte black background at a distance of 0.45 m. The camera was connected to the USB port of a PC with a Remote Capture Software (version 2.7.2, Canon, USA) to visualize and receive the digitized images directly from the computer. The camera and four fluorescent 15 W lamps (Neon OSRAM TLD65-15W, Germany) were placed inside a wooden box with black internal surfaces to exclude external light and reflection, and the box was located in the laboratory at room temperature (20 °C), adjacent to the cold room where samples were stored.

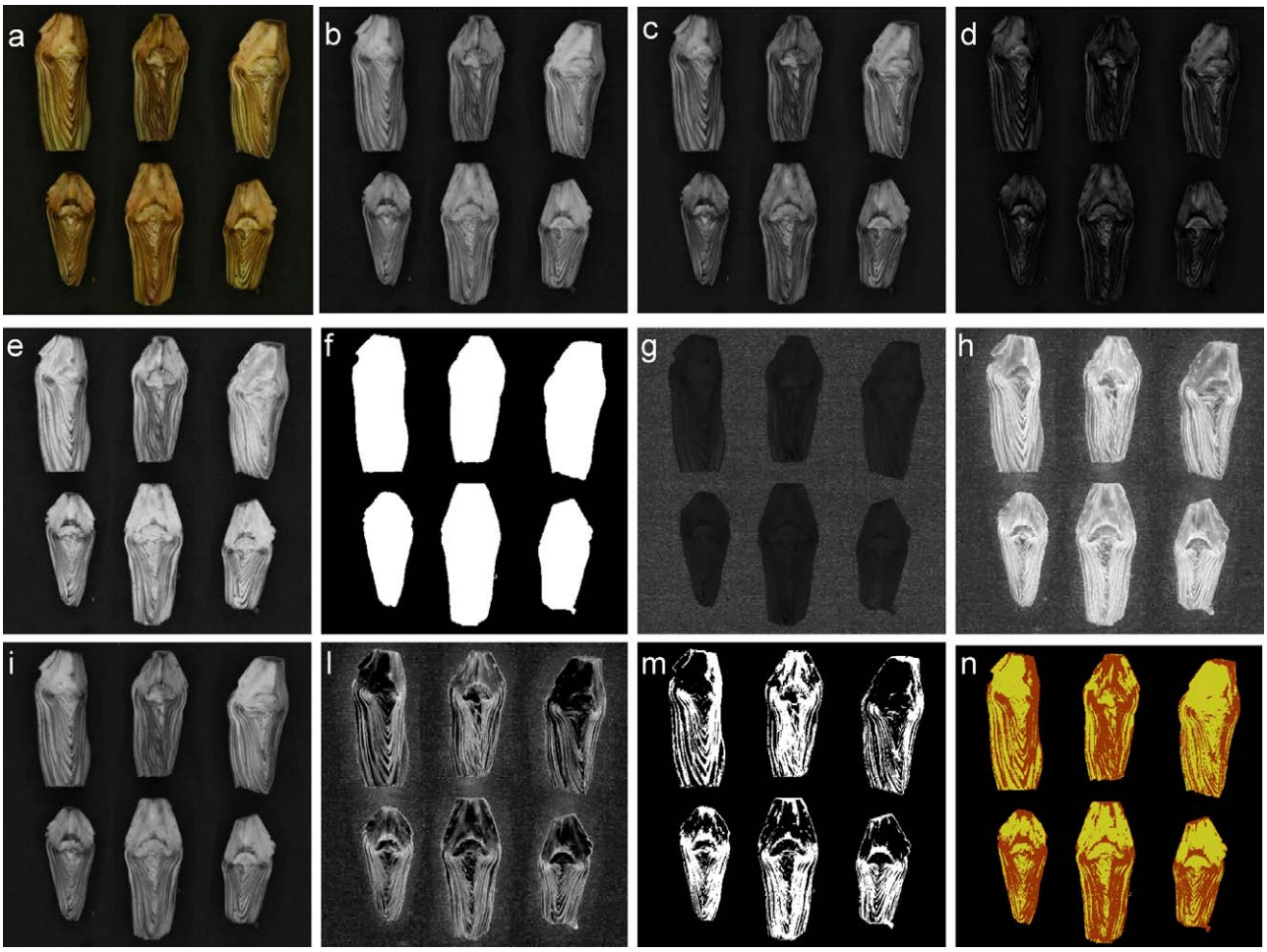


Fig. 1. Output images representing each step of the image segmentation algorithm: (a) original RGB image; (b) red component image 'R'; (c) green component image 'G'; (d) blue component image 'B'; (e) enhanced image obtained by adding 'R' to 'G' and subtracting 'B'; (f) binary image 'mask1' where '0' (black) is the background and '1' (white) is the region of interest (whole artichoke); (g) Hue component image 'H'; (h) Saturation component image 'S' (i) Value component image 'V'; (l) enhanced image obtained by subtracting 'V' to 'S'; (m) binary image 'mask2', where '0' (black) is the not browned area and '1' (white) the region of interest (browned area); (n) false-colour mask with browned (brown) and not browned (yellow) area.

For each sample, 6 artichokes pieces were acquired in the same image with the following camera setting: manual exposure mode with the lens aperture value at $f = 6.3$, speed 1/4, resolution of 3888×2592 pixels, and storage in TIFF format. All the algorithms for image segmentation, colour space conversion, and colour measurements were performed using the MATLAB® v7.0 (MathWorks, USA) image processing toolbox (MathWorks, 2010).

To isolate the artichoke quarters (Fig. 1a) from the background in the RGB image, a thresholding segmentation approach was developed. In Fig. 1, an example of the process for the segmentation of 6 artichoke quarters is shown. Contrast enhancement was achieved generating a grey-scale image obtained by adding the red and the green component images (Fig. 1b and c), and subtracting the blue component image (Fig. 1d). This image (Fig. 1e) was thresholded using the Otsu method (Otsu, 1979), and a flood filling operation (Soille, 1999) was performed to fill the holes in the thresholded image (Fig. 1f). This is a binary image, namely mask1, where '0' (black) is the background and '1' (white) the interest region, i.e. the whole artichoke quarters. From this binary image, the localization of the interest region pixels permitted the computation of the colour of the whole artichoke quarters.

To partition the region of interest into browned areas and background, i.e. non-browned areas in the whole artichoke quarters, a second thresholding segmentation approach was developed. The RGB image was converted into the HSV colour space using the '*rgb2hsv*' function included in the MATLAB image processing toolbox (MathWorks, 2010) and the Hue, Saturation and Value image components (Fig. 1g–i) were separated. Contrast enhancement was achieved generating a new grey-scale image by subtracting the Value image component (Fig. 1i) from the Saturation image component (Fig. 1h), since the browned area showed high S value and low V values, while the non-browned area showed low S and high V values. This image (Fig. 1l) was then thresholded into the interest region using mask1 and the Otsu method, and the resulting image (Fig. 1m) is a binary image, namely mask2, where '0' (black) is the background, i.e. the non-browned areas, and '1' (white) the interest region, i.e. browned areas. From this binary image, the localization of the pixels of the interest region permitted the extraction from the original image of the colour of the browned areas of the artichoke quarters.

The RGB image was converted into the L*a*b* colour space using the '*srgb2lab*' function included in the MATLAB image processing toolbox and the lightness, redness, and yellowness component images were separated for the whole quarter surface and for the browned area (L^*_{brown}, a^*_{brown} and b^*_{brown}). The extent of browning was computed as the ratio of the number of pixels with value '1' in binary image mask2 and the number of pixels with value '1' in binary image mask1.

Table 2
Effect of the anti-browning treatment on colour attributes and appearance score of artichoke quarters during storage at 5 °C.

Treatment (Experiment 1)	Score	L*	a*	b*	L^*_{brown}	a^*_{brown}	b^*_{brown}	Browning extent (%)
CTRL	3.1	42.9	2.2	32.9	30.4	4.9	31.3	47.6
0.5% NaCl	3.1	42.3	2.1	33.2	30.3	4.7	31.7	45.0
1% NaCl	3.2	43.2	1.7	33.7	31.3	4.3	32.3*	44.9
0.5% CA	3.1	43.1	3.5*	33.6	31.1	6.8*	32.4*	44.7
1% CA	3.1	39.9*	4.9*	32.9	29.2	8.2*	31.3	47.5
0.5% AA	3.1	43.1	3.1*	33.9*	30.9	6.2*	32.3*	43.5
1% AA	3.1	42.7	3.3*	34.5*	31.7*	6.2*	33.0*	45.3
0.5% EtOh	3.0	43.4	2.1	33.4	31.0	5.0	31.7	43.4
1% EtOh	3.0	42.9	2.7	33.9*	31.0	5.4	32.4*	44.2
0.25% CYS	3.6*	45.4*	3.2*	39.9*	35.3*	6.2*	37.8*	47.0
0.5% CYS	3.6*	47.1*	3.5*	41.2*	37.4*	6.8*	39.7*	44.6
0.01% 4HR	2.8*	38.1*	3.4*	32.3	27.5*	5.6*	30.0*	53.0*

Within each column values followed by * are statistically different ($P < 0.05$) from the untreated samples (CTRL), according to Dunnet test. Mean values of the entire storage duration (n images = 12).

2.4. Statistical analysis

To determine the effect of treatment and storage time a two-way ANOVA ($P < 0.05$) was carried out with the SAS software (Sas Institute, Inc., V 8.2, Cary, NC, USA). Mean quality attributes for each treatment were compared to the control samples (CTRL) using the Dunnet test. Due the number of treatments, results of the Dunnet test on appearance score, were used to discriminate among dippings. Following, colour data means of treatments significantly different from CTRL, were separated for each storage time, using the Tukey test.

Regression coefficients, and p values of standard regression between score values and individual colour parameters (L*, a* and b*, obtained from image analysis, including browning percentage), were found for each experiment using Statgraphics Plus software (ver. 5.1, Statistical Graphics Corp., Warrenton, VA, USA). In addition a calibration and a validation set of data containing 126 images each (representing every treatment and storage duration), were generated across the two experiments, for appearance score prediction using colour parameters, using a linear model.

3. Results

3.1. Experiment 1

In Table 2 are reported the results of the Dunnet test on the values of colour parameters and appearance score for Experiment 1, as mean values for all the storage durations.

With regard to appearance score, 0.25% CYS, 0.5 and 0.01% 4-HR gave different results from the CTRL treatment; artichokes treated with 0.01% 4-HR scored worse than the control, while samples treated with cysteine received a score significantly higher than CTRL samples. Treatment with 0.01% 4HR also induced more browning, while no other difference was observed for this parameter. Results of the Dunnet test on appearance score were used to discriminate among treatments. Tables 3 and 4 show L* and b*values at each storage duration, only for the dipping resulted different from the CTRL.

In general, treatments with cysteine solutions (all concentrations) induced less pronounced browning, as can be observed by the highest L^*_{brown} value which were significantly higher than the control up to 48 h (36.7 vs 30.6), while differences in L* values of the whole quarter surface were less significant. Artichokes treated with 0.01% 4HR had the lowest L* values after 24 h, but with continuing storage, no differences were detected compared to CTRL samples.

It is interesting to note that 3 h after dipping, artichokes treated with cysteine had L* values higher than the initial value, and this was also associated with an increase in the b* values (yellowness) (Table 4). CYS 0.25% and CYS 0.5% treatments also resulted in an increase in b* values for both the whole quarter surface and browned areas, noticeable from the first 3 h, and maintained higher b* values than the CTRL up to the end of the experiment. In Fig. 2, comparison of appearance of CTRL and CYS 0.5% samples after 3 h from dipping is shown.

Table 3
Effect of the anti-browning treatment on L*values of artichoke quarters and of the browned area (L^*_{brown}) during storage at 5 °C.

Treatment (Experiment 1)	3 h	24 h	48 h	120 h
L* ($T0 = 50.92$)				
CTRL	46.3 b	44.1 ab	43.6 a	37.6 ab
0.01% 4HR	40.1 c	40.0 c	38.1 b	34.2 b
0.25% CYS	52.2 a	46.4 ab	44.4 a	38.4 a
0.5% CYS	54.5 a	49.6 a	45.9 a	38.9 a
L^*_{brown} ($T0 = 35.9$)				
CTRL	32.8 b	32.1 b	30.6 b	26.3 ab
0.01% 4HR	29.0 c	28.9 b	27.6 b	24.4 b
0.25% CYS	40.7 a	37.0 a	34.5 a	29.1 a
0.5% CYS	42.6 a	39.9 a	367.0 a	30.3 a

Within each column values followed by different letters are statistically different ($P < 0.05$), according to Tukey test. Mean values of each storage duration (n images = 3).

3.2. Experiment 2

Data of experiment 2 (Table 5) show that all cysteine-containing treatments and 1% AA resulted in a higher appearance score compared to the CTRL treatment. In addition, artichokes treated with cysteine had higher L* values compared to the CTRL, while L* value of samples treated with 1% AA was not statistically different from CTRL samples. On the other hand, 2% AA, and 1% and 2% CA, had higher values of a* and a^*_{brown} compared to the CTRL, indicating an

Table 4
Effect of the anti-browning treatment on b*values of artichoke quarters and of the browned area (b^*_{brown}) during storage at 5 °C.

Treatment (Experiment 1)	3 h	24 h	48 h	120 h
b* ($T0 = 35.58$)				
CTRL	34.0 b	34.0 b	32.5 b	31.2 b
0.01% 4HR	33.5 c	33.1 b	31.7 b	30.8 b
0.25% CYS	41.5 a	41.6 a	40.2 a	36.3 a
0.5% CYS	42.0 a	43.1 a	41.8 a	38.0 a
b^*_{brown} ($T0 = 34.42$)				
CTRL	32.9 b	33.0 b	31.2 b	28.2 b
0.01% 4HR	31.7 c	31.2 b	29.7 b	27.6 b
0.25% CYS	40.2 a	39.6 a	37.9 a	33.4 a
0.5% CYS	41.4 a	41.9 a	40.4 a	35.1 a

Within each column values followed by different letters are statistically different ($P < 0.05$), according to Tukey test. Mean values of each storage duration (n images = 3).

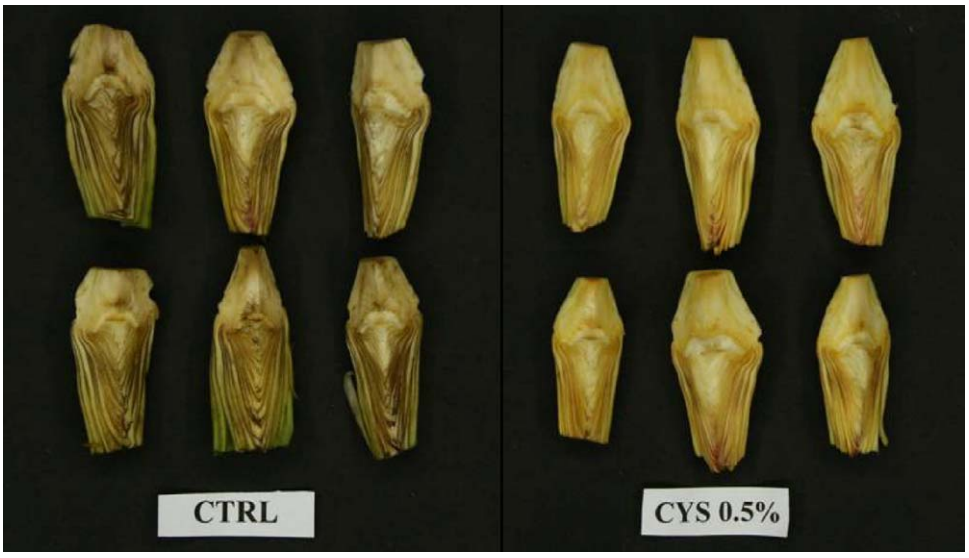


Fig. 2. Fresh-cut artichokes after 3 h from cutting and dipping in water (CTRL), and in cysteine at 0.5% (0.5% CYS).

Table 5
Effect of the anti-browning treatment on colour attributes and appearance score of artichoke quarters during storage at 5 °C.

Treatment (Experiment 2)	Score	L*	a*	b*	L^*_{brown}	a^*_{brown}	b^*_{brown}	Browning extent (%)
CTRL	2.7	37.2	3.3	32.4	27.0	4.8	29.7	50.7
2% CA	2.8	35.1	6.3*	31.2	25.5	8.6*	28.7	52.5
1% CA	2.8	36.9	5.4*	32.5	26.9	7.4*	29.9	51.8
2% AA	2.8	39.3*	4.3*	33.1	28.3	6.4*	30.7	49.4
1% AA	3.0*	38.7	4.1*	33.2	28.0	6.0	30.8	49.2
1% CYS	3.3*	43.6*	4.5*	39.7*	34.1*	7.3*	37.6*	48.8
0.5% CYS	3.4*	42.9*	4.6*	39.0*	33.6*	7.4*	37.2*	47.7
0.5% CYS pH 3	3.6*	45.4*	3.5	42.5*	37.1*	5.9*	40.6*	43.2*
CA + AA + CYS	3.1*	40.3*	4.5*	34.7	30.4	6.9*	32.7*	49.5

Within each column values followed by * are statistically different ($P < 0.05$) from the untreated samples (CTRL), according to Dunnet test. Mean values of the entire storage duration (n images = 12).

increase of the red component, and therefore of browning, even if it was not detected in visual appearance. With regard to the browned area, only 0.5% CYS pH3 induced a significantly lower extent of browning (%).

In this experiment 1% CYS, 0.5% CYS, and 0.5% CYS pH3 were effective in delaying the L* decrease on the whole quarter surface up to 48 h (Table 6). Moreover all cysteine treatments showed L^*_{brown} values higher than in CTRL samples until 48 h, being 17% (1% and 0.5% CYS) and 32% (0.5% CYS pH3) higher than in the CTRL. Moreover for the last dipping, L^*_{brown} values were significantly higher than the CTRL (27%) up to the end of the experiment (120 h). Also in this experiment, a b* increase was observed for cysteine treated samples; after 3 h 0.5% CYS pH 3 induced the highest b* value on both whole and browned areas, about 30% higher than the initial value. Differences in b* values between cysteine treated samples (0.5%, 1% and 0.5% CYS pH3) and CTRL samples were noticeable until the end of storage (Table 7).

Table 6
Effect of the anti-browning treatment on L* values of artichoke quarters and of the browned area (L^*_{brown}) during storage at 5 °C.

Treatment (Experiment 2)	3 h	24 h	48 h	120 h
L* (*T0* = 49.92)				
CTRL	43.0 b	39.2 d	36.1 d	30.7 ab
1% AA	45.4 b	40.8 cd	37.0 cd	31.4 ab
CA + AA + CYS	58.0 a	39.9 d	34.5 d	28.8 b
1% CYS	57.5 a	44.9 ab	39.5 bc	32.6 ab
0.5% CYS	54.8 a	44.2 bc	40.1 ab	32.6 ab
0.5% CYS pH	3 55.0 a	48.2 a	43.1 a	35.4 a
L^*_{brown} (*T0* = 35.6)				
CTRL	31.6 b	28.6 c	26.2 d	21.5 bc
1% AA	33.6 b	30.3 c	26.2 cd	21.9 bc
CA + AA + CYS	44.7 a	30.2 c	26.1 d	20.6 c
1% CYS	45.8 a	35.8 ab	30.7 b	24.1 ab
0.5% CYS	43.2 a	35.8 ab	30.7 b	24.8 ab
0.5% CYS pH	3 46.2 a	40.3 a	34.5 a	27.4 a

Within each column values followed by different letters are statistically different ($P < 0.05$), according to Tukey test. Mean values of each storage duration (n images = 3).

3.3. Correlation among colour parameters and appearance score

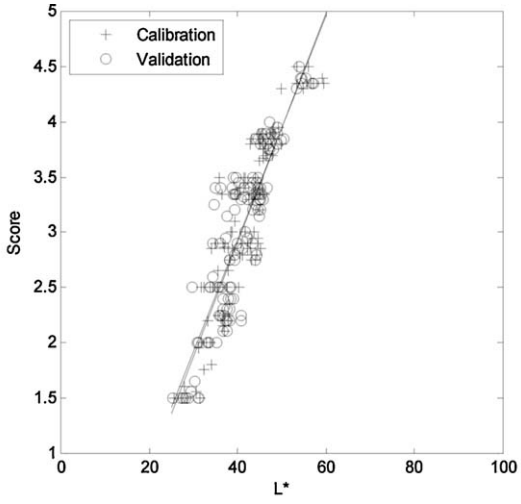
For all colour parameters (L*, a*, and b*) obtained by image analysis, comprising colour measures on the whole surface and on the browned area, a standard regression was performed in order to find a possible correlation with appearance score as evaluated by the human eye. Correlation coefficients with the P-value for each colour parameter and for the browning area percentage, calculated for each experiment, are reported in Table 8.

All colour parameters and browning incidence showed a statistically significant relationship ($P > 0.0001$) with the appearance score. L* measured on the whole quarter surface showed the highest correlation coefficients of 0.90 and 0.92 in the two experiments. L^*_{brown} and b^*_{brown} also showed relatively high correlation coefficients (0.77 and 0.80 respectively for the first experiment, and 0.91 and 0.89 for the second), while the a* value was the parameter less correlated with the appearance score. In addition a* values and browning percentage were negatively correlated with appearance score (showing negative correlation coefficients). In the second

Table 7
Effect of the anti-browning treatment on b* values of artichoke quarters quarters and of the browned area (b^*_{brown}) during storage at 5 °C (*T0* = initial value).

Treatment (Experiment 2)	3 h	24 h	48 h	120 h
b* (*T0* = 36.57)				
CTRL	35.1 c	33.5 c	32.0 c	29.3 bc
1% AA	36.5 c	34.9 c	32.3 c	29.0 c
CA + AA + CYS	41.7 b	35.1 c	33.1 c	29.0 c
1% CYS	43.6 b	42.6 ab	39.2 ab	33.3 a
0.5% CYS	42.9 b	42.0 b	38.4 b	32.7 ab
0.5% CYS pH 3	47.3 a	45.3 a	41.8 a	35.6 a
b^*_{brown} (*T0* = 36.63)				
CTRL	33.4 c	30.9 b	29.2 c	25.6 c
1% AA	35.4 c	32.7 b	29.5 c	25.5 c
CA + AA + CYS	42.2 b	32.9 b	30.4 c	25.4 c
1% CYS	44.4 ab	40.0 a	36.1 b	29.9 a
0.5% CYS	42.9 b	40.0 a	35.7 b	30.2 a
0.5% CYS pH 3	46.9 a	43.7 a	39.3 a	32.7 a

Within each column values followed by different letters are statistically different ($P < 0.05$), according to Tukey test. Mean values of each storage duration (*n* images = 3).



Model Parameters	n	R	P	RMSE	Intercept	Slope		n	RMSE
Calibration	*126*	0.9	<0.0001	0.33	-1.11421	0.101348	*Validation*	126	0.34

Fig. 3. Predicted vs observed values of appearance score of fresh-cut artichokes (validation data set) during storage at 5 °C and model parameters.

experiment, L^*_{brown} showed a correlation coefficient comparable to that of L* for the whole section, and in general higher correlation coefficients were found for this experiment.

For validation of the method a model for appearance score prediction by image analysis was built. The model obtained with the calibration data set, with data representing all treatments and storage duration across the two experiments, confirmed a significant ($P < 0.0001$) linear regression between L* values and measured appearance score, as reported in Fig. 3, which also shows the distribution of calibration and validation data constructed starting for L* values of the whole quarters.

4. Discussion

Results of this study showed that cysteine was the most efficient anti-browning compound in preventing browning of fresh-cut artichokes; when the natural pH of the 0.5% cysteine solution was increased to pH 3 its antibrowning efficacy was enhanced. Samples treated with cysteine received the highest appearance scores in both experiments and induced an initial increase in L* and b* values, that subsequently decreased during storage, with final values more similar to the initial values than those observed for the other treatments. It is probable that the retention of these two parameters during storage was the reason for the highest acceptance of this treatment. Several other studies have confirmed the effects of cysteine in controlling browning of plant tissues (Son et al., 2001; Gorny et al., 2002; Perez-Gago et al., 2006). In particular, Rocculi et al. (2007) found that this thiol-containing amino acid was a more efficient browning inhibitor than citric and ascorbic acids on fresh-cut potatoes, and also observed an increase in L* and in the whitening index for fresh-cut potatoes treated with cysteine.

Different hypotheses for the mechanism of action have been proposed. Firstly cysteine is reported to reduce o-quinones to their phenol precursors (Cilliers and Singleton, 1990); then it is suggested that it forms stable bounds with the copper of active PPO sites directly inhibiting the enzyme (Kahn, 1985); finally Richard-Forget et al. (1991), isolated cysteine-quinone addition compounds from different phenols that almost block the browning reaction, showing high affinity with PPO enzymes, and subtracting substrates for the further oxidation of o-quinone. The increase in treatment pH to 3 from the natural value of 2.1, induced better colour retention of the artichoke quarters, and this may be due to the fact that at higher pH values, the nucleophilic attack of quinones by cysteine is more effective due to the pK_a of thiol group (Richard-Forget et al., 1991; Gorny et al., 2002). It may be interesting to test the effect of higher pH values of cysteine solutions on browning of cut artichokes. In addition, since in these experiments sensory acceptance was not evaluated, further studies should address the impact of cysteine on organoleptic characteristics of cut artichokes.

As for the other dippings, previous studies have reported that the application of 4-hexyl-resorcinol was less effective than ascorbic acid and cysteine in reducing browning of fresh-cut apples (Perez-Gago et al., 2006), while Lattanzio et al. (1989) found both citric and ascorbic acid at 1% were effective in improving quality and shelf-life of the stored artichoke heads. In the present study, ascorbic acid showed some effect on delaying browning of cut-artichokes, but its efficacy was lower than cysteine, and could be observed only up to 3 h after cutting, while citric acid had a post-cutting performance not different or even worse than for control samples. These different findings may be explained by the higher extent of mechanical damage on artichoke quarters compared to the minimal cutting used for whole artichoke heads, and also by the different browning mechanism of mechanically damaged

Table 8
Regression coefficients between appearance score and colour parameters (L*, a*, b*, and browning extend) obtained by CSV.

	Correlation coefficients	
	First experiment	Second experiment
Whole quarters		
L*	0.90****	0.92****
a*	−0.69****	−0.63****
b*	0.70****	0.86****
Browned area		
L^*_{brown}	0.88****	0.91****
a^*_{brown}	−0.52****	−0.32****
b^*_{brown}	0.81****	0.89****
Browning extent (%)	−0.68****	−0.74****

ns, not significant.
*$P \leq 0.05$.
**$P \leq 0.01$.
***$P \leq 0.001$.
**** $P \leq 0.0001$.

artichokes, compared to undamaged heads (Lattanzio et al., 1994). The lower efficacy of ascorbic acid at 2% and of citric acid, compared to untreated samples, has also been reported by other authors and can be explained by a stimulation of PPO activity, as reported by Jiang et al. (2004) for concentrations of citric acid lower than 0.04 M (about 1%, w/w) in Chinese water chestnuts, or by the induction of important oxidative damage as caused by ascorbic acid in fresh-cut 'Fuji' apples (Larrigaudière et al., 2008).

It was also possible to measure the colour of fresh-cut artichoke quarters, which at present has been instrumentally measured only on selected points of the receptacle (Melilli et al., 2004; Cabezas-Serrano et al., 2009) or on the outer surface of the bracts (Raccuia and Melilli, 2004), which might not be representative of the whole cut surface, since browning normally occurs at the cutting edges. In fact L* values reported by these authors (not being an average of the whole surface) were higher than values obtained in the present study. In addition it must be considered that the low L* values obtained by this method are due to the different conditions of the measurements, and particularly the type of light source and the distance between the camera and sample, which is negligible when using a colorimeter. In order to take into account the whole surface appearance, Cabezas-Serrano et al. (2009) introduced among other evaluations, a score on a 5-point subjective anchored scale, which is frequently used on other fresh-cut produce (Amodio et al., 2007). Image analysis may be therefore used as support for laboratory experiments aimed to assess colour measurements on cut artichokes, and as in this case to select an effective anti-browning treatment, as for other applications in food research, such as evaluation of colour and browning incidence of basil leaves (Peri et al., 2005), and muscle colour and marbling features on beef (Jackman et al., 2009; Chen et al., 2010).

The colour indexes L*, a* and b* for the whole quarter surface and browned area were all well correlated with appearance scores as evaluated by the human eye with the aid of a subjective scale; specifically L*values measured on the whole quarter surface showed the highest correlation with appearance scores, and were used as predictors of appearance for the validation of the method, showing good performance in term of *r* correlation coefficients and *P* values. This is in agreement with the general finding of a decrease in L* values associated with development of browning (Gorny et al., 2002; Yoruk et al., 2004; Rico et al., 2007; Quevedo et al., 2009). As for variation of a* and b* values, the association with browning is not always consistent, but is most probably related to the kind of product used. Perez-Gago et al. (2006) observed an increase in a* and b* values in browning apples, Rinaldi et al. (2004) observed a decrease in b* and an increase in a* values in cut melons, while Quevedo et al. (2009) observed a decrease in b* and a stable a* value during the browning process of cut bananas. The highest correlation of L* values with appearance also suggested that the measurement of L* on whole quarters was more representative of the overall appearance of the cut artichokes as observed by the human eye. L* and b* were positively correlated with appearance score, while the increase in a* values was negatively correlated with score, due to the development of a red component in the colour of the artichokes during storage. Also for the percentage of browned area, a negative correlation was found, but the correlation coefficient was lower compared to that of L* and b* values, most probably because human perception was more influenced by the intensity of the browning than by the extension of the browned area. Image analysis is a very rapid technique consisting of collecting images of the samples that may be elaborated afterwards, and requiring little time for colour measurement and data recollection; this will also reduce the risk of sample browning during colour acquisition.

References

Ahvenainen, R., 1996. New approaches in improving the shelf life of minimally processed fruit and vegetables. Trends Food Sci. Technol. 7, 179–186.

Amodio, M.L., Cabezas-Serrano, A.B., Rinaldi, R., Colelli, G., 2007. Implementation of rating scales for visual quality evaluation of various vegetable crops. In: Kader, A.A., Cantwell, M. (Eds.), Produce Quality Rating Scales and Colour Charts (Appendix 1). University of California, Davis, CA, USA, Postharvest Horticulture Series No. 23.

Amodio, M.L., Rinaldi, R., Colelli, G., 2006. Influence of atmosphere composition on quality attributes of ready-to- cook fresh-cut vegetable soup. Acta Hortic. 712, 677–684.

Amodio, M.L., Colelli, G., 2008. Effect of thermal treatment and dipping on quality and shelf-life of fresh-cut peaches. Adv. Hortic. Sci. 1, 21–26.

Brosnan, T., Sun, D.W., 2004. Improving quality inspection of food products by computer vision––a review. J. Food Eng. 61, 3–16.

Buta, J.G., Abbott, J.A., 2000. Browning inhibition of fresh-cut 'Anjou' 'Bartlett', and 'Bosc' pears. HortScience 35, 1111–1113.

Cabezas-Serrano, A.B., Amodio, M.L., Cornacchia, R., Rinaldi, R., Colelli, G., 2009. Screening quality and browning susceptibility of 5 artichoke cultivars for fresh-cut processing. J. Sci. Food Agric. 89, 2588–2594.

Chen, K., Sun, X., Qin, Ch., Tang, X., 2010. Colour grading of beef fat by using computer vision and support vector machine. Comput. Electron. Agric. 70, 27–32.

Choi, Y.J., Tomás-Barberán, F.A., Saltveit, M.E., 2005. Wound-induced phenolic accumulation and browning in lettuce (*Lactuca sativa* L.) leaf tissue in reduced by exposure to n-alcohols. Postharvest Biol. Technol. 37, 47–55.

Cilliers, J.J.L., Singleton, V.L., 1990. Caffeic acid autoxidation and effect of thiols. J. Agric. Food Chem. 38, 1789–1896.

Del Nobile, M.A., Conte, A., Scrocco, C., Laverse, J., Brescia, I., Conversa, G., Elia, A., 2009. New packaging strategies to preserve fresh-cut artichoke quality during refrigerated storage. Innov. Food Sci. Emerg. Technol. 10, 128–133.

Garcia, E.L., Barrett, D.M., 2002. Preservative treatments for fresh-cut fruits and vegetables. In: Lamikanra, O. (Ed.), Fresh-Cut Fruits and Vegetables. Science, Technology and Market. CRC Press, pp. 267–303.

Giménez, M., Olarte, C., Sanz, S., Lomas, C., Echávarri, J.F., Ayala, F., 2003. Relation between spoilage and microbiological quality in minimally processed artichoke packaged with different films. Food Microbiol. 20, 231–242.

González-Aguilar, G.A., Wang, C.Y., Buta, J.G., 2001. Inhibition of browning and decay of fresh-cut radishes by natural compounds and their derivatives. Lebensm. Wiss. Technol. 34, 324–328.

Gorny, J.R., Hess-Pierce, B., Cifuentes, R.A., Kader, A.A., 2002. Quality changes in fresh-cut pear slices as affected by controlled atmospheres and chemical preservatives. Postharvest Biol. Technol. 24, 271–278.

Gorny, J.R., Cifuentes, R.A., Hess-Pierce, B.H., Kader, A.A., 2000. Quality changes in fresh-cut pear slices as affected by cultivar, ripeness stage, fruit size and storage regime. J. Food Sci. 65, 541–544.

Gunasekaran, S., 1996. Computer vision technology for food quality assurance. Trends Food Sci. Technol. 7, 245–255.

Guerrero-Beltrán, J.A., Swanson, B.G., Barbosa-Cánovas, G.V., 2005. Inhibition of polyphenoloxidase in mango puree with 4-hexylresorcinol, cysteine and ascorbic acid. LWT Food Sci. Technol. 38, 625–630.

Hutchings, J.B., 1999. Food Color and Appearance. Aspen Publishers Inc., U.S.

Jackman, P., Sun, D., Allen, P., 2009. Automatic segmentation of beef longissimus dorsi muscle and marbling by an adaptable algorithm. Meat Sci. 83, 187–194.

Janovitz-Klapp, A.H., Richard-Forget, C., Goupy, P.M., Nicolas, J.J., 1990. Inhibition studies on apple polyphenol oxidase. J. Agric. Food Chem. 38, 926–931.

Jiang, Y., Pen, L., Li, J., 2004. Use of citric acid for shelf life and quality maintenance of fresh-cut Chinese water chestnut. J. Food Eng. 63, 325–328.

Kahn, V., 1985. Effect of proteins, protein hydrolyztes and amino acids on o-dihydroxyphenolases of polyphenol oxidase of mushroom, avocado, and banana. J. Food Sci. 59, 111–115.

Lambrecht, H.S., 1995. Sulfite substitutes for the prevention of enzymatic browning in foods. In: Lee, C.Y., Whitaker, J.R. (Eds.), Enzymatic Browning and Its Prevention. American Chemical Society, USA, pp. 313–323.

Lattanzio, V., Linsalata, V., Palmieri, S., Van Sumere, C.F., 1989. The beneficial effect of citric and ascorbic acid on the phenolic browning reaction in stored artichokes (*Cynara scolymus* L.) heads. Food Chem. 33, 93–106.

Lattanzio, V., Cardinali, A., Di Venere, D., Linsalata, V., Palmieri, S., 1994. Browning phenomena in stored artichoke (*Cynara scolymus* L.) heads: enzymic or chemical reaction? Food Chem. 50, 1–7.

Leon, K., Mery, D., Pedreschi, F., Leon, J., 2006. Colour measurement in L*a*b* units from RGB digital images. Food Res. Int. 39, 1084–1091.

Larrigaudière, C., Ubach, D., Soria, Y., Rojas-Graü, M.A., Martín-Belloso, O., 2008. Oxidative behaviour of previous termfreshnext term-ctu 'Fuji' apples treated with stabilising substances. J. Sci. Food Agric. 88, 1170–1776.

MathWorks, 2010. Matlab Images Processing Toolbox, Revised for Version 7.0 (Release 2010a), Available Online at http://www.mathworks.com/access/helpdesk/help/toolbox/images/, last accessed May 10, 2010.

Melilli, M.G., Raccuia, S.A., Riggi, E., 2004. Effect of cold storage on color changes in globe artichokes [*Cynara cardunculus* L. subsp. scolymus (L.) Hegi] head tissues. Acta Hortic. 660, 557–561.

Moline, H.E., Buta, J.G., Newman, I.M., 1999. Prevention of browning of banana slices using natural products and their derivatives. J. Food Qual. 22, 499–511.

Monsalve-Gonzalez, A., Barbosa-Canovas, G.V., McEvily, A., Iyengar, R., 1995. Inhibition of enzymatic browning in apple products by 4-hexylresorcinol. Food Technol. 49, 110–118.

Otsu, N., 1979. A threshold selection method from gray-level histogram. IEEE Trans. SMC-15, 652–655.
O'Sullivan, M.G., Byrne, D.V., Martens, H., Gidskehaug, L.H., Andersen, H.J., Martens, M., 2003. Evaluation of pork colour: prediction of visual sensory quality of meat from instrumental and computer vision methods of colour analysis. Meat Sci. 65, 909–918.
Papadakis, S.E., Abdul-Malek, S., Kamdem, R.E., Yam, K.L., 2000. A versatile and inexpensive technique for measuring color of foods. Food Technol. 5, 48–51.
Perez-Gago, M.B., Serra, M., Del Rio, M.A., 2006. Colour change of fresh-cut apples coated with whey protein concentrate-based edible coatings. Postharvest Biol. Technol. 39, 84–92.
Peri, G., Romaniello, R., Colelli, G., Amodio, M.L., 2005. Misurazione della qualità dei prodotti orticoli in foglia mediante analisi d'immagine. Atti del convegno AIIA 2005, 241.
Quevedo, R., Díaz, O., Ronceros, B., Pedreschi, F., Aguilera, J.M., 2009. Description of the kinetic enzymatic browning in banana (*Musa cavendish*) slices using non-uniform color information from digital images. Food Res. Int. 42, 1309–1314.
Raccuia, S.A., Melilli, M.G., 2004. Genetic influence on browning kinetics of globe artichoke [*Cynara cardunculus* L. subsp. scolymus (L.) Hegi]. Acta Hortic. 660, 557–561.
Richard-Forget, C., Goupy, P.M., Nicolas, J.J., Lacombe, J.M., Pavia, A.A., 1991. Cysteine as an inhibitor of enzymatic browning 1. Isolation and characterization of addition compounds formed during oxidation of phenolics by apple polyphenol oxidase. J. Agric. Food Chem. 39, 841–847.
Richardson, T., Hyslop, D.B., 1985. Enzymes. In: Fennema, O.R. (Ed.), Food Chemistry. Dekker, New York, pp. 371–476.
Rico, D., Martín-Diana, A.B., Barat, J.M., Barry-Ryan, C., 2007. Extending and measuring the quality of fresh-cut fruit and vegetables: a review. Trends Food Sci. Technol. 18, 373–386.
Rinaldi, R., Amodio, M.L., Colelli, G., 2004. Effects of calcium treatment and modified atmosphere on postharvest life of fresh-cut 'campsol' melons. Adv. Hortic. Sci. 2, 85–88.
Rocculi, P., Gómez Galindo, F., Mendoza, F., Wadsö, L., Romani, S., Dalla Rosa, M., Sjöholm, I., 2007. Effects of the application of anti-browning substances on the metabolic activity and sugar composition of fresh-cut potatoes. Postharvest Biol. Technol. 43, 151–157.
Soille, P., 1999. Morphological Image Analysis—Principles and Applications. Springer-Verlag.
Son, S.M., Moon, K.D., Lee, C.W., 2001. Inhibitory effects on various antibrowning agents on apple slices. Food Chem. 73, 23–30.
Tomás-Barberán, F.A., Espín, J.C., 2001. Phenolics compounds and related enzymes as determinants of quality in fruits and vegetables. J. Sci. Food Agric. 81, 853–876.
Tortoe, C., Orchard, J., Beezer, A., 2007. Prevention of enzymatic browning of apple cylinders using different solutions. Int. J. Food Sci. Technol. 42, 1475–1481.
Yoruk, R., Yoruk, S., Balaban, M.O., Marshall, M.R., 2004. Machine vision analysis of antibrowning potency for oxalic acid: a comparative investigation on banana and apple. J. Food Sci. 69, E281–E289.

Capítulo 6

Capítulo 6. OPTIMIZACIÓN DEL TRATAMIENTO ANTIOXIDANTE CON CISTEINA PARA SU APLICACIÓN EN ALCACHOFA IV GAMA

6.1. EFFECT OF SOLUTION PH OF CYSTEINE-BASED PRE-TREATMENTS TO PREVENT BROWNING OF FRESH-CUT ARTICHOKES. POSTHARVEST BIOLOGY AND TECHNOLOGY 75, 17-23 (2013)

Postharvest Biology and Technology 75 (2013) 17–23

Contents lists available at SciVerse ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Effect of solution pH of cysteine-based pre-treatments to prevent browning of fresh-cut artichokes

A.B. Cabezas-Serrano[1], M.L. Amodio, G. Colelli*

Dip.to PRIME, Università degli Studi di Foggia, via Napoli 25, 71122 Foggia, Italy

ARTICLE INFO

Article history:
Received 17 April 2012
Accepted 22 July 2012

Keywords:
Phenols
PPO activity
Appearance
Storage

ABSTRACT

Fresh-cut artichokes were treated with cysteine in the form of aqueous solutions of L-cysteine hydrochloride monohydrate at 0.5% (w/v) normal pH 2.2 adjusted to different pH values with NaOH (from 2 to 7). General appearance and colour measurements during storage at 5 °C showed different degrees of suppression of darkening on cut surfaces. Cysteine pre-treatments caused an increase in the yellow index (b^* value) of fresh-cut artichokes compared to untreated samples, which was more pronounced at lower pH (47.9 versus the initial value of 28.3 after 1 day). Artichokes treated at lower pH values also had a lower appearance score and higher PPO activity than artichokes treated at higher values, closer to neutrality. Starting from 3 days of storage a negative correlation between solution pH and PPO activity was also observed, that for artichokes treated with cysteine at pH 7 was lower than for control samples. L-cysteine pre-treatments did not affect total phenolic content and antioxidant activity of fresh-cut artichokes, which showed an increasing pattern after 8 days. These data may represent an important step in prevention of browning in fresh-cut artichokes.

1. Introduction

Artichoke (*Cynara scolymus* L.) is a source of phenolic compounds, inulin, fibres and minerals (Wang et al., 2003; Orlovskaya et al., 2007) and for this reason it is considered as a functional food (Lattanzio et al., 2009). The increasing interest in functional foods by consumers have led fresh-cut processors to have a special interest in this crop which could represent an excellent alternative combining "health" and "convenience".

One of the most important causes of quality loss in minimally processed artichokes is browning of the cut surface, where phenolic compounds are involved (Lattanzio et al., 1989). In general, the major enzyme responsible for the browning reactions is polyphenol oxidase (PPO), a copper-containing enzyme which also catalyses the ortho-hydroxylation of monophenols and the oxidation of *o*-diphenols to *o*-quinones (Lee and Whitaker, 1995).

Few approaches have been conducted to inhibit browning process in fresh artichokes despite its high browning potential. Lattanzio et al. (1989) investigated the use of citric and ascorbic acids to delaying browning of stored artichokes heads; more recently, Giménez et al. (2003) and Del Nobile et al. (2009) tested ascorbic acid and edible coatings containing citric acid, respectively, on minimally processed artichokes. However the use of ascorbic acid and citric acid provides only temporary prevention of browning (Özoglu and Bayindirli, 2002). Recently Amodio et al. (2011), in a study where different compounds were tested, reported that ascorbic acid had little effect on delaying browning of cut artichokes, which could be observed only up to 3 h after cutting, whereas citric acid had a post-cutting effect not different from control samples. On the other hand, these authors reported that cysteine at 0.5% was the most effective treatment to prevent browning, and its effectiveness was improved by increasing the pH of the solution from 2.2 to 3.

Cysteine is a very effective inhibitor for PPO (Eidhin et al., 2005), however, its action is complex; during oxidation, cysteine traps the *o*-quinones by forming colourless products (cysteinyl adducts) that has been proved to be competitive inhibitors of PPO (Richard-Forget et al., 1992). Different studies have evaluated the efficiency of cysteine as an anti-browning agent on fresh-cut vegetables and fruit (Dorantes-Álvarez et al., 1998; Guerrero-Beltrán et al., 2005; Rojas-Graü et al., 2006), either individually or in mixtures with organic acids, showing different results. Some authors (Gorny et al., 2002; Vilas-Boas and Kader, 2006; Rocculi et al., 2007; Larrigaudière et al., 2008) have pointed out undesirable effects of cysteine on appearance and metabolism of fresh cut products that could be related to several factors such as its concentration and pH of the solution. In addition, results of Amodio et al. (2011), who observed that increasing the pH from 2 to 3 was beneficial in

* Corresponding author. Tel.: +39 0881589105.
E-mail address: g.colelli@unifg.it (G. Colelli).
[1] Present address: Departamento de Bromatología y Tecnología de los Alimentos, Universidad de Córdoba, 14001 Cordoba, Spain.

0925-5214/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.postharvbio.2012.07.006

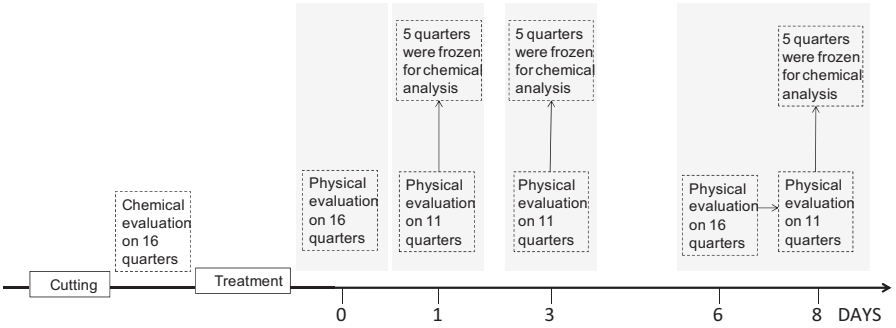


Fig. 1. Graphical representation of sampling for a single replicate/treatment.

preventing browning of cut artichokes, raised the need to investigate the effect of a wider range of pH of cysteine solution on preventing browning. Therefore the objective of the present work was to study the effect of the pH of 0.5% cysteine solutions on browning potential of fresh-cut artichokes.

2. Material and methods

2.1. Raw material and processing

Artichokes (*C. scolymus* L. cv. 'Catanese') were harvested in southern Italy (Brindisi area) and transported by car to the Postharvest Laboratory of the University of Foggia where they were processed the same day. Processing was performed in a cold room at 10 °C under hygienic conditions (i.e. all bench surface, utensils and plastic containers were washed and disinfected with sodium hypochlorite). For each treatment 2 replicates consisting of 16 artichoke hearts were used.

For each artichoke, the external bracts, leaves and stalk were removed; heads were then washed in a NaOCl solution (100 ppm of free chlorine) to eliminate remains of soil and insects. After washing, head trimming was completed further removing external greener and tougher bracts (inedible fraction) until only the receptacle and the more tender, inner bracts, remained. The artichoke hearts were cut into four lengthwise slices (quarters). Cut artichokes were placed in a plastic colander and dipped in ice water containing 100 ppm sodium hypochlorite. The quarters (64 per replicate and treatment) were then drained and randomly selected for different treatments/replicates. Artichoke quarters were then immersed for 1 min at 20 °C in a solution containing distilled water (CTRL), L-cysteine hydrochloride monohydrate 0.028 M (0.5%, w/v) at natural pH of about 2.2 (CYS-pH2), or L-cysteine hydrochloride monohydrate at the same concentration and different pH (from 3 to 7) obtained by adding enough NaOH (4 M) and denoted as CYS-pH3, CYS-pH4, CYS-pH5, CYS-pH6, CYS-pH7. After treatment, quarters were gently dried by hand with cheesecloth, and groups of 16 quarters were placed in 4 plastic clamshells at 5 °C which were used for samplings, as shown in Fig. 1.

Colour and overall appearance were evaluated soon after treatment (day 0) and after 1, 3, 6, and 8 days of storage. For untreated samples at day 0 and for all samples after 1, 3, and 8 days of storage, subsamples of 5 quarters per replicate were frozen in liquid nitrogen and stored at −80 °C for further chemical analyses (Fig. 1).

2.2. Quality evaluations

All quality evaluation procedures were performed at ambient temperature (about 20 °C). The same 11 quarters per replicate were used for general appearance evaluation and colour measures. The overall appearance was evaluated by a group of six people. Artichoke quarters of each replicate were presented to the judges on a black surface. Quarters were evaluated subjectively on a 5 to 1 scale, where 5 = excellent, no defects; 4 = very good, minor defects; 3 = fair, moderate defects; 2 = poor, major defects; 1 = unedible. A score of 3 was considered as the limit of marketability and a score of 2 as the limit of edibility (Amodio et al., 2007).

The colour of artichoke quarters was measured on three different points on the receptacle. Colour measurements were conducted by means of a portable spectrophotometer (CM2600, Konica Minolta Sensing, Osaka, Japan) testing $L^*a^*b^*$ parameters in CIE scale and calculating Hue angle = arctg (b^*/a^*). Calibration of the instrument was performed by means of the measurement of a white tile (white calibration) and a zero calibration. The following settings were used: 100% UV; illuminant D65; observer angle 10°; measurement area 8 mm.

2.3. Total phenol content and antioxidant activity

Analysis of total phenols and antioxidant activity were performed on the same extract. Five grams per replicate of artichoke frozen samples were homogenized with Ultraturrax (IKA, T18 Basic, USA) in methanol–water solution (80:20) plus 2 mM sodium fluoride for 1 min, and then centrifuged at 5 °C and 12,000 × *g* for 10 min. The pellet was discarded and the supernatant was used as the extract for the total phenol content and the antioxidant activity determinations.

Total phenols were determined according to the method of Singleton and Rossi (1965). Each extract (100 μL) was mixed with 1.58 mL water, 100 μL of Folin–Ciocalteau's reagent and 300 μL of sodium carbonate solution (200 g/L). After 2 h standing, the absorbance was read at 575 nm against a blank with a spectrophotometer (Shimadzu UV-1700l, China). Content of total phenols was calculated on the basis of the calibration curves of gallic acid, and was expressed as milligrams of gallic acid equivalents (GAE) per 100 g of fresh weight (mg GAE/100 g FW). All extracts were analysed three times.

The antioxidant assay was performed following the procedure described by Brand-Williams et al. (1995), with minor modifications. 100 μL of the diluted extract (dilution 1:20) were pipetted into 0.9 mL of DPPH solution to start the reaction. The absorbance was read after 20 min at 515 nm. Trolox was used as a standard and the antioxidant activity was reported in mM of Trolox equivalents per 100 g of fresh weight (mM TEAC/100 g FW). All extracts were analysed three times.

2.4. PPO activity

The methodology was adapted from that of Cantos et al. (2002). Briefly, 5 g of frozen artichoke tissue for each replicate were homogenized with a Ultraturrax (IKA, T18 Basic, USA) in 20 mL of cold 0.1 M sodium phosphate buffer (pH 7) containing 3% Triton X-114 (v/v), 1 mM phenylmethanesulfonyl fluoride (PMSF), 5 mM

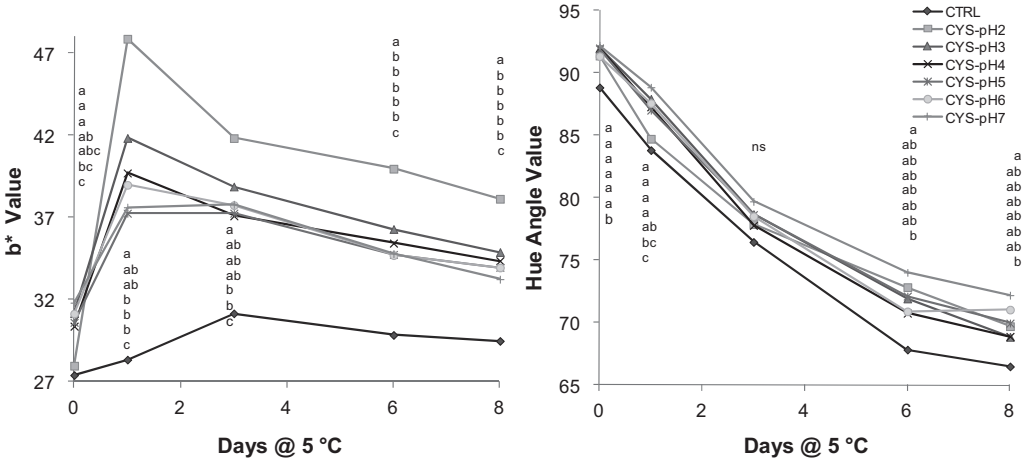


Fig. 3. Hue angle and b^* values of fresh-cut artichokes treated with HCL L-cysteine monohydrate solutions (0.5%, w/v, at different pH values) stored at 5 °C for 8 days. Within the same storage evaluation, different letters indicate statistical differences, $P \leq 0.05$.

still above the limit of marketability. After 8 days, artichokes dipped in CYS-pH7 had statistically better appearance compared to artichokes treated with CYS-pH2.

Artichokes quarters dipped in cysteine had significantly higher b^* values compared to control samples, immediately after dipping, as shown in Fig. 3. The yellow index exhibited a noticeable increase in L-cysteine-treated artichokes 1 day after the treatment and then decreased starting from 3 days of storage whereas the b^* value in control samples showed a little increase up to 3 days and then remained almost constant. After 3 days of storage and up to the end, artichokes treated with CYS-pH2 maintained an higher b^* value than control sample, whereas samples treated at lower pHs showed intermediate values.

Changes of Hue angle values of artichokes quarters are shown in Fig. 3. After dipping, control samples had the lowest value compared to the other samples; after 1 day CTRL and CYS-pH2 samples exhibited statistically lower values compared to all other samples. At the end of storage, untreated samples had statistically lower Hue angles than samples treated with cysteine at neutral pH (66.5 versus 72.2), while no significant differences were found among all other treatments.

3.2. *Effect of* L-*cysteine pre-treatment at different pH conditions on PPO activity of fresh-cut artichokes*

Treatment and storage time had a significant influence and contributed to the PPO activity of fresh cut artichokes at significance levels reported in Table 2, and so did their interaction. PPO activity was monitored throughout storage as an indicator of the effects of the different pH of the cysteine solutions on the enzymatic browning of fresh cut artichokes (Fig. 4). In general, it was observed that PPO activity of artichokes treated with CYS-pH 7 was inhibited during storage, particularly after 8 days of storage. The first day after treatment, a significant decrease of PPO activity was observed for artichokes treated with CYS-pH7, CYS-pH2 and CYS-pH3, compared to the initial value (1.5 enzyme units, not included in the graph of Fig. 4). In contrast, artichokes samples treated with cysteine at pH 6, pH 4, pH 5 and control samples showed an increase of PPO activity compared to initial value. At day 3, artichokes dipped in CYS-pH 2 and CYS-pH 3 and CYS-pH4 exhibited a remarkable increase in PPO activity, and particularly samples treated with CYS-pH2 showed a PPO activity statistically higher than those of artichokes treated with cysteine at pH 5, pH 6 and pH 7. At day 8, residual PPO activity was lower than at day 3, with artichokes treated with CYS-pH7 and CYS-pH5 showing a statistically lower PPO activity than artichokes dipped in CYS-pH2. A significant exponential regression was found between PPO activity and pH of the solution (from 2 to 7) at day 3 and 8 (with coefficient of regression of −0.96 and −0.86, with p values less than 0.01 and 0.05, respectively), whereas at day 1 the regression did not have a significant value. These results indicated that PPO activity significantly decreased with the increase of the pH of the cysteine solution, starting from 3 days of storage.

3.3. *Effect of* L-*cysteine pre-treatment at different pH conditions on total phenol content and antioxidant activity of fresh-cut artichokes*

The pH of the solution, and generally the treatment, did not affect total phenol content and antioxidant activity of fresh cut artichokes whereas storage time had a significant influence on both these attributes (Table 2). At day 1, an increase in total phenol content compared to the initial value was observed (367.3 versus 328.4 mg GAE/100 g FW). After 3 days of storage,

Table 2
Effect of treatment and time of storage on phenolic content, antioxidant activity and PPO activity of fresh-cut artichokes. When interaction among factors was not significant, the results of the mean separation test (Tukey test) are reported (different upper case letters indicate statistical difference within treatment and time of storage, respectively, for $P \leq 0.05$).

	Phenolics (mg GAE/100 g FW)	AOX (mM TEAC/100 g FW)	PPO activity (Enzymatic Units)
CTRL	365.9	5.0	1.9
CYS-pH2	393.5	5.5	1.7
CYS-pH3	380.7	6.2	1.4
CYS-pH4	332.6	4.1	1.8
CYS-pH5	350.4	5.6	1.6
CYS-pH6	352.6	5.6	1.4
CYS-pH7	341.3	5.1	1.0
0	328.4	4.7	1.6
1	367.3B	4.7B	1.8
3	299.7C	4.8B	2.1
8	411.8A	6.4A	0.8
A: Treatment	ns	ns	*
B: Storage time	****	****	**
Interaction A×B	ns	ns	**

ns, not significant.
* $P \leq 0.05$.
** $P \leq 0.01$.
*** $P \leq 0.001$.
**** $P \leq 0.0001$.

total phenol content decreased in all treatments, and at the end of the storage there was a general increase of total phenol content for all treatment as shown in Table 2 (411.8 mg GAE/100 g FW). In addition at 8 days of storage a significant coefficient of correlation of 0.86 ($P < 0.05$) was found between phenols and PPO activity, indicating that PPO activity increased with the increasing of phenol content (data not shown).

Also, antioxidant activity was statistically higher at the end of storage, increasing from 4.7 mM TEAC/100 g FW at day 0 to 6.4 after 8 days of storage.

4. Discussion

Results of this experiment showed a different degree of suppression of darkening on cut surfaces of artichokes resulting from treatments with cysteine in the form of an aqueous solution of HCL L-cysteine monohydrate 0.5% (w/v) at different pH values.

Measurement of reflectance as Hue angle, which is considered a measure of cut surface darkening (Gorny et al., 2002), showed that non-treated artichokes had statistically higher rates of darkening during the entire storage time compared to those treated with cysteine at pH 7. Hue angle values decreased after 8 days from a bright yellow colour (close to 90°) to a brownish yellow, varying from about 66° for untreated samples to 72° when CYS-pH7 solution was used. Cabezas-Serrano et al. (2009a,b) also reported the decrease of Hue angle associated with browning of fresh-cut 'Catanese' artichokes, together with a variation in a^* and L^* values. In this study pattern of increasing of a^* values and a decrease in luminosity were observed during storage of fresh-cut artichokes in accordance with that reported by Giménez et al. (2003) on stored fresh artichoke heads, and by Cabezas-Serrano et al. (2009a,b). Hence, it might be that lower values of luminosity and higher a^* values observed for artichokes treated with CYS-pH2 and CTRL were induced by a minor effect of inhibiting browning of cut surfaces. In addition, an increase of the b^* value was associated with cysteine treatments, and particularly for the treatment at pH 2. Amodio et al. (2011) reported a greater increase of the yellow index for artichokes treated with cysteine solution at pH 3 than at pH 2, whereas in the present work the higher b^* value was observed in samples treated at pH 2. Moreover Amodio et al. (2011) found that cysteine treatment at 0.5% and natural pH was effective in delaying browning of cut artichokes and that its efficiency increased with the increase of the pH of the solution. In the present work CYS-pH2 was not so effective in delaying browning, showing values comparable to control samples for most of the quality attributes, whereas the effect of the pH of the solution was confirmed, indicating a higher anti-browning efficiency of the cysteine at higher pH, particularly at pH 7. Differences between the studies could be due to the fact that response of artichokes to the same treatments may be affected by other factors such as preharvest factors, which have been shown to affect many quality attributes of fresh artichokes (Massignan et al., 2005; Mauromicale et al., 2005; Todaro et al., 2010).

Several authors have investigated the use of L-cysteine, with no pH modification, to control the extent of browning in fresh-cut fruit and vegetables with different results. Tortoe et al. (2007) observed a higher incidence of browning on fresh-cut apples treated with cysteine (0.025 M) than for apples treated with other anti-browning agents, whereas Buta et al. (1999), Son et al. (2001), Guerrero-Beltrán et al. (2005) and Perez-Gago et al. (2006) reported the inhibitive effect of cysteine on browning of fresh-cut apples and mango puree. The mechanism of action of cysteine is complex, and different hypotheses have been proposed. Firstly, cysteine is reported to reduce o-quinones to their phenol precursors (Cilliers and Singleton, 1990). It has also been suggested that it forms stable bonds with the copper of active PPO sites directly inhibiting the enzyme (Khan, 1985). Finally, Richard-Forget et al. (1991) isolated cysteine–quinone addition compounds from different phenols that almost block the browning reaction, showing high affinity with PPO enzymes, and subtracting substrates for the further oxidation of o-quinone. It has also been observed that after the exhaustion of cysteine, and in an excess of o-quinones, cysteine–quinone adducts are further co-oxidized with regeneration of phenol precursors, leading to a final colour, dependent on the main phenol substrate. This is bright orange for chlorogenic acid, violet for 4-methylcathecol and pink for epicatechines (Richard-Forget et al., 1992). The bright yellow colour observed for cut artichokes may therefore be explained by further oxidation of cysteine–quinone compounds, that induced a final colour that was more acceptable than control samples, where phenols were directly oxidized by PPO.

As for the effect of the pH of the cysteine solution, previous studies reported different results depending on product assayed. Dorantes-Álvarez et al. (1998) observed a better retention of colour of minimally processed avocados dipped in L-cysteine when the solution pH decreased to acidic conditions from 6.5 to 3.5. In contrast, Gorny et al. (2002) reported that the use of a pre-treatment solution containing L-cysteine at pH 7 on fresh cut pears improved the anti-browning effect compared to the same pre-treatment at pH 3, and controlled the development of a pinkish colour observed

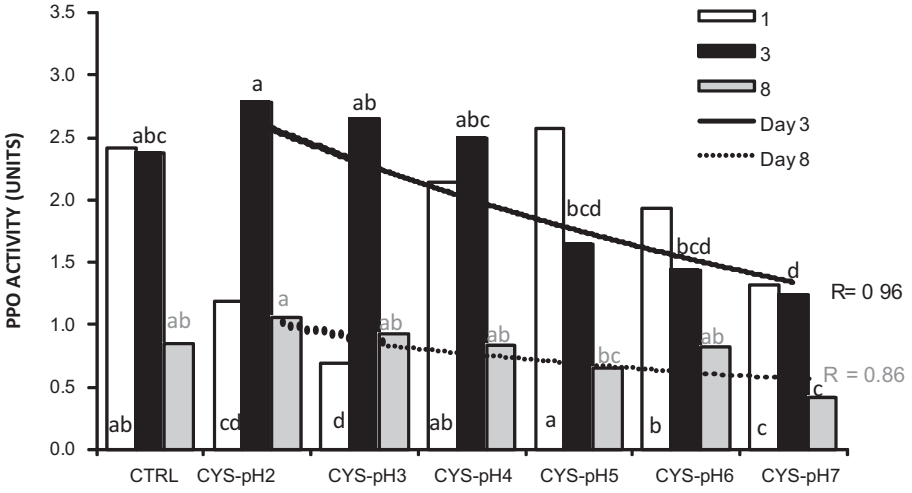


Fig. 4. PPO activity of fresh-cut artichokes treated with HCL L-cysteine monohydrate solutions at 0.5% (w/v) at different pH values after 1, 3 and 8 days of storage at 5 °C. Within the same storage evaluation, different letters indicate statistical differences, $P \leq 0.05$. Solid and dotted line indicate the exponential regression of PPO activity over pH (from 2 to 7) at 3 and 8 days of storage respectively (no significant regression was found after 1 day).

when treating pears with cysteine solution without pH correction. Vilas-Boas and Kader (2006) observed for fresh-cut banana, lower browning with L-cysteine solutions at low pH values and Gomez-Lopez et al. (2008) showed better appearance in fresh cut lettuce and cabbage treated with a HCL L-cysteine solution (pH 6.5). On the other hand, Rocculi et al. (2007) observed that the application of L-cysteine to fresh-cut potatoes led to an increase in their metabolic activity after treatment, whereas Gomez-Lopez et al. (2008) pointed out a decrease in metabolic activity when lettuce and cabbage were treated with a HCL-cysteine solution (pH 6.5). Lambers et al. (1998) have previously reported that metabolic activity is a pH dependent phenomenon increasing at low pH values. The higher metabolic activity rate at acidic pH conditions may therefore help to explain the negative changes on overall appearance of CYS-pH 2-treated artichokes. Son et al. (2001) also suggested that cysteine at pH 7 inhibited non-enzymatic browning in apple slices, which can partially explain the minor changes observed in colour and general appearance of fresh-cut artichokes treated with cysteine at pH 7 conditions. Non-enzymatic browning is also known to cause browning of artichokes due to the oxidation of the iron stored as ferritin in the chloroplast forming a dark complex with phenols, and particularly with chlorogenic acid, even though enzymatic browning is expected to be the leading browning process in cut tissues (Lattanzio et al., 1994).

Finally the results on PPO activity showed that after 1 day of storage, PPO activity was lower in artichokes treated with cysteine solutions at lower pH values (2 and 3), followed by artichokes treated at pH 7, whereas starting from 3 days of storage a significant negative correlation was observed for PPO activity and pH, indicating that PPO activity decreased with the increase of the pH of the cysteine solution, being lower for artichokes treated with cysteine at pH 7 than for untreated samples.

Since sulphites and thiol compounds act also as reducing agents at pH below 4 (Cilliers & Singleton, 1990; Gorny et al., 2002), it can be also hypothesized that after 1 day in artichokes treated at pH 2 and 3, L-cysteine acted principally as a reducing agent and that this effect was temporary, since oxidation of cysteine is not reversible. With the increasing storage time, it can be supposed that the reducing effect was exhausted and that in acidic conditions the thiol-group of L-cysteine was not so effective in forming complexes with quinones and, therefore, in inhibiting secondary oxidation and polymerization reactions.

As for phenol content and antioxidant activity, no effect of the cysteine treatments was observed. Initial phenol content (328.4 mg GA/100 g FW) was comparable to that reported by other authors. Dogan et al. (2005) observed 425 mg catechol/100 g in the edible part of an unidentified artichoke cultivar, whereas Gil-Izquierdo et al. (2001) reported for 'Blanca de Tudela' a total phenol content of 193.5 mg/kg. In general, an increasing pattern in total phenol content of artichokes the day after processing was observed. These results differ from those described by Richard-Forget et al. (1992) who showed a decrease in phenolic compounds during enzymatic oxidation in the presence of cysteine, when an in vitro assay was performed, since phenols were blocked by the thiol group of cysteine. However, it may be assumed that the behaviour of phenolic compounds in the presence of cysteine might present some modifications when assayed on fresh-cut products since the wounding stress induces the phenylpropanoid pathway, as observed by Tomás-Barberán et al. (1997) in lettuce or by Reyes and Cisneros-Zevallos (2003) in potatoes. After this increase, a general decrease in total phenolics was observed that can be explained by the oxidation of phenolics (Lattanzio et al., 1994; Ferracane et al., 2008), as confirmed also by the increase of PPO activity in all samples, or also by the formation of cysteine adducts (Altunkaya and Gökmen, 2009) in samples treated at high pHs, in which the reduction of phenols is not therefore necessarily a sign of phenol oxidation. An increase of phenol content was observed at day 8. At this time, phenol content was positively correlated with PPO activity as reported by other authors on fresh-cut potato (Cabezas-Serrano et al., 2009a,b), indicating a higher enzymatic activity stimulated by the higher presence of substrates.

Only few studies have reported the effect of L-cysteine on total phenol content during storage of fresh-cut products. Altunkaya and Gökmen (2009) assaying the changes in chlorogenic acid concentration in presence of cysteine (among other inhibitors) in fresh cut lettuce, observed that degradation rates with cysteine were almost the same as in the control, but that no browning was observed for cysteine-treated samples, thus supporting the hypothesis of formation of cysteine adducts with phenols.

No differences in antioxidant activity were observed among treatments despite the fact that several authors have reported the action of cysteine as a free radical scavenger because of the presence of a thiol group (Darkwa et al., 1998; Bassil et al., 1999; Altunkaya and Gökmen, 2008), but probably this is due to the high phenol content of artichokes which may have greatly affected the total antioxidant activity which was not sensitive to the cysteine supplement.

5. Conclusion

Colour and general appearance of fresh cut artichokes were affected by pH of L-cysteine hydrochloride monohydrate pretreatment solutions. An increase of yellow colour was observed in all L-cysteine-treated artichokes, which was more visible at low pH values. Also in these conditions, a lower general appearance was observed. On the contrary, fresh-cut artichokes treated with L-cysteine at pH 7 showed best appearance and lowest changes in colour attributes, due to the higher inhibition of PPO activity. Acidic conditions (pH 2 and pH 3) only led to a temporary inhibition effect on PPO, which did not avoid undesirable colour changes on cut surfaces. These results may represent an important step in prevention of browning of fresh-cut artichokes.

References

Altunkaya, A., Gökmen, V., 2009. Effect of various anti-browning agents on phenolic compounds profile of fresh lettuce (*L. sativa*). Food Chemistry 117, 122–126.
Altunkaya, A., Gökmen, V., 2008. Effect of various inhibitors on enzymatic browning, total phenol content and total antioxidant activity of lettuce. Food Chemistry 107, 1173–1179.
Amodio, M.L., Cabezas-Serrano, A.B., Rinaldi, R., Colelli G., 2007. Implementation of rating scales for visual quality evaluation of various vegetable crops. In: Kader, A.A., Cantwell, M. (Eds.), Produce Quality Rating Scales and Color Charts. University of California Postharvest Horticulture Series No. 23, Davis, CA, USA (Appendix 1).
Amodio, M.L., Cabezas-Serrano, A.B., Peri, G., Colelli, G., 2011. Post-cutting quality changes of fresh-cut artichokes treated with different anti-browning agents as evaluated by image analysis. Postharvest Biology and Technology 62, 213–220.
Bassil, D., Makris, D.P., Kefalas, P., 1999. Oxidation of caffeic acid in the presence of L-cysteine: isolation of 2-S-cystinylcaffeic acid and evaluation of its antioxidant properties. Food Research International 38, 395–402.
Brand-Williams, W., Cuvelier, M.E., Berset, C., 1995. Use of a free radical method to evaluate antioxidant activity. Lebensmittel-Wissenschaft & Technologie 28, 25–30.
Buta, J.G., Moline, H.M., Spaulding, D.W., Wang, C.Y., 1999. Extending storage life of fresh-cut apples using natural products and their derivates. Journal of Agricultural and Food Chemistry 47, 1–6.
Cabezas-Serrano, A.B., Amodio, M.L., Cornacchia, R., Rinaldi, R., Colelli, G., 2009a. Suitability of five different potato cultivars (*Solanum tuberosum* L.) to be processed as fresh-cut products. Postharvest Biology and Technology 53, 138–144.
Cabezas-Serrano, A.B., Amodio, M.L., Cornacchia, R., Rinaldi, R., Colelli, G., 2009b. Screening quality and browning susceptibility of five artichoke cultivars for fresh-cut processing. Journal of the Science of Food and Agriculture 89, 2588–2594.
Cantos, E., Tudela, J.A., Gil, M.I., Espín, J.C., 2002. Phenolic compounds and related enzymes are not rate-limiting in browning development of fresh-cut potatoes. Journal of Agricultural and Food Chemistry 50, 3015–3023.
Cilliers, J.J.L., Singleton, V.L., 1990. Caffeic acid autoxidation and effects of thiols. Journal of Agricultural and Food Chemistry 38, 1789–1796.

Darkwa, J., Mundoma, C., Simoti, R.H., 1998. Antioxidant chemistry reactivity and oxidation of DL-cysteine by some common oxidants. Journal of the Chemical Society – Faraday Transactions 94, 1971–1978.

Del Nobile, M.A., Conte, A., Scrocco, C., Laverse, J., Brescia, I., Conversa, G., Elia, A., 2009. New packaging strategies to preserve fresh-cut artichoke quality during refrigerated storage. Innovative Food Science and Emerging Technology 10, 128–133.

Dogan, S., Turan, Y., Ertürk, H., Arslan, O., 2005. Characterization and purifications of polyphenol oxidase from artichoke (*Cynara scolymus* L.). Journal of Agricultural and Food Chemistry 53, 776–785.

Dorantes-Álvarez, L., Parada-Dorantes, L., Ortiz-Moreno, A., Santiago Pineda, A., Chiral-Boix, S., Barbosa Cánovas, G., 1998. Effect of anti-browning compounds on the quality of minimally processed avocados. Food Science and Technology International 4, 107–113.

Eidhin, D.M., Murphy, E., O'beirne, D., 2005. Polyphenoloxidase from apple (*Malus domestica* Borkh. Cv Bramley's Seedling): purification strategies and characterization. Journal of Food Science 7, 51–58.

Ferracane, R., Pellegrini, N., Visconti, A., Graziani, G., Chiavaro, E., Miglio, C., Fogliano, V., 2008. Effect of different cookings methods on antioxidant profile, antioxidant capacity, and physical characteristics of artichoke. Journal of Agricultural and Food Chemistry 56, 8601–8608.

Gil-Izquierdo, A., Gil, M.I., Conesa, M.A., Ferreres, F., 2001. The effect of storage temperatures on vitamin C and phenolics content of artichoke (*Cynara scolymus* L.) heads. Innovative Food Science and Emerging Technology 2, 199–202.

Giménez, M., Olarte, C., Sanz, S., Lomas, C., Echávarri, J.F., Ayala, F., 2003. Relation between spoilage and microbiological quality in minimally processed artichoke packaged with different films. Food Microbiology 20, 231–242.

Gomez-Lopez, V.M., Ragaert, P., Jeyachchandran, V., Debevere, J., Devlieghere, F., 2008. Shelf-life of minimally processed lettuce and cabbage treated with gaseous chlorine dioxide and cysteine. International Journal of Food Microbiology 121, 74–83.

Gorny, J.R., Hess-Pierce, B., Cifuentes, R.A., Kader, A.A., 2002. Quality changes in fresh-cut pear slices as effected by controlled atmosphere and chemical preservatives. Postharvest Biology and Technology 24, 271–278.

Guerrero-Beltrán, J.A., Swanson, B.G., Barbosa-Cánovas, G.V., 2005. Inhibition of polyphenoloxidase in mango puree with 4-hexylresorcinol, cysteine and ascorbic acid. Lebensmittel-Wissenschaft & Technologie 38, 625–630.

Khan, V., 1985. Effect of proteins, protein hydrolytes and amino acids on o-dihydroxyphenolases of polyphenol oxidase of mushroom, avocado, and banana. Journal of Food Science 59, 111–115.

Lambers, H., Chapin III, F.S., Pons, T.L., 1998. Plant Physiological Ecology. Springer, New York.

Larrigaudière, C., Ubach, D., Soria, Y., Rojas-Graü, M.A., Martin-Belloso, O., 2008. Oxidative behavior of fresh-cut 'Fuji' apples treated with stabilising substances. Journal of Food Science 88, 1770–1776.

Lattanzio, L., Cardinali, A., Di Venere, D., Linsalata, V., Palmieri, S., 1994. Browning phenomena in stored artichoke (*Cynara scolymus* L.) heads: enzymic or chemical reactions? Food Chemistry 50, 1–7.

Lattanzio, V., Kroon, P.A., Linsalata, V., Cardinali, A., 2009. Globe artichoke: a functional food and source of nutraceutical ingredients. Journal of Functional Foods 1, 131–144.

Lattanzio, V., Linsalata, V., Palmieri, S., Van Sumere, C.F., 1989. The beneficial effect of citric and ascorbic acid on the phenolic browning reaction in stored artichoke (*Cynara scolymus* L.) heads. Food Chemistry 33, 93–106.

Lee, C.Y., Whitaker, J.R., 1995. Enzymatic Browning and its Prevention. ACS Symposium Series, American Chemical Society, Washington, DC, pp. 2–22.

Massignan, L., Lovino, R., Di Venere, D., Linsalata, V., 2005. Effect of harvest time, processing and packaging on the quality of 'Ready to use' artichokes. Acta Horticulturae 681, 629–636.

Mauromicale, G., Ierna, A., Licandro, P., 2005. Harvest time and yield of globe artichoke in relation to the production environment of plantlets. Acta Horticulturae 681, 117–125.

Orlovskaya, T.V., Luneva, I.L., Chelombit'ko, V.A., 2007. Chemical composition of *Cynara scolymus* leaves. Chemistry of Natural Compounds 43, 239–240.

Özoglu, H., Bayindirli, A., 2002. Inhibition of enzymatic browning in cloudy apple juice with selected antibrowning agents. Food Control 13, 213–221.

Perez-Gago, M.B., Serra, M., Del Rio, M.A., 2006. Colour change in fresh-cut apples coated with whey protein concentrate-based edible coatings. Postharvest Biology and Technology 39, 84–92.

Reyes, L.F., Cisneros-Zevallos, L., 2003. Wounding stress increases the phenolic content and antioxidant capacity of purple-flesh potatoes (*Solanum tuberosum* L.). Journal of Agricultural and Food Chemistry 51, 5296–5300.

Richard-Forget, C., Goupy, P.M., Nicolas, J.J., Lacombe, J.M., Pavia, A.A., 1991. Cysteine as an inhibitor of enzymatic browning. 1. Isolation and characterization of addition compounds formed during oxidation of phenolics by apple polyphenol oxidase. Journal of Agricultural and Food Chemistry 39, 841–847.

Richard-Forget, F.C., Goupy, P.M., Nicolas, J.J., 1992. Cysteine as an inhibitor of enzymatic browning. 2. Kinetic studies. Journal of Agricultural and Food Chemistry 40, 2108–2113.

Rocculi, P., Gómez Galindo, F., Mendoza, F., Wadsö, L., Romani, S., Dalla Rosa, M., Sjöholm, I., 2007. Effects of the application of anti-browning substances on the metabolic activity and sugar composition of fresh-cut potatoes. Postharvest Biology and Technology 43, 151–157.

Rojas-Graü, M.A., Sobrino López, A., Tapia, M.S., Martin-Belloso, O., 2006. Browning inhibition in fresh-cut 'Fuji' Apple slice by natural antibrowning agent. Journal of Food Science 71, 59–65.

Singleton, V.L., Rossi, J.A., 1965. Colorimetry of total phenolics with phosphomolybdic–phosphotungstic acid reagents. American Journal of Enology and Viticulture 16, 144–158.

Son, S.M., Moon, K.D., Lee, C.Y., 2001. Inhibitory effects of various antibrowning agents on apple slices. Food Chemistry 73, 23–30.

Tomás-Barberán, F.A., Loaiza-Velarde, J., Bonfanti, A., Saltveit, M.E., 1997. Early wound- and ethylene-induced changes in phenylpropanoid metabolism in harvested lettuce. Journal of the American Society for Horticultural Science 122, 399–404.

Todaro, A., Peluso, O., Catalano Eghle, A., Mauromicale, G., Spagna, G., 2010. Polyphenol oxidase activity from three Sicilian artichoke [*Cynara cardunculus* L. Var. scolymus L. (Fiori)] cultivars: studies and technological application on minimally processed production. Journal of Agricultural and Food Chemistry 58, 1714–1718.

Tortoe, C., Orchard, J., Beezer, A., 2007. Prevention of enzymatic browning of apple cylinders using different solutions. International Journal of Food Science and Technology 42, 1475–1481.

Vilas-Boas, E.V.d.B., Kader, A.A., 2006. Effect of atmospheric modification, 1-MCP and chemicals on quality of fresh-cut banana. Postharvest Biology and Technology 39, 155–162.

Wang, M., Simon, J.E., Aviles, I.F., He, K., Zheng, Q., Tadmor, Y., 2003. Analysis of antioxidative phenolic compounds in artichoke (*Cynara scolymus* L.). Journal of Agricultural and Food Chemistry 51, 601–608.

Capítulo 7

Chapter 7. CONCLUSIONS

The main conclusions that can be drawn based on the research carried out, the proposed strategies and the results obtained during the development of this Doctoral Thesis are described below.

1. Enzymatic browning is the main factor limiting quality and storability of fresh-cut potato and artichokes. In order to develop a strategy to limit browning susceptibility the selection of the most suitable cultivar to be processed as fresh-cut product is the first step to be explored. Results of this thesis contributed to increase knowledge on the suitability of potato and artichokes cultivars to be processed as fresh cut, pointing out the importance of the cultivar choice a on the final product. Different chemical compositions among cultivars, in fact, leaded to different post-cutting performances other than different nutritional values. [*The above conclusion was drawn from the articles: "Suitability of five different potato cultivars (Solanum tuberosum L.) to be processed as fresh-cut products". Postharvest Biology and Technology 53 (2009) 138–144; "Suitability of 4 potato cultivars (Solanum tuberosum L.) to be processed as fresh-cut product. Early cultivars.* American *Journal of Potato Research 88 (2011) 403–411; "Screening quality and browning susceptibility of five artichoke cultivars for fresh-cut processing. Journal of the Science of Food and Agriculture 89 (2009) 2588–2594*].

2. Among the late potato cultivars tested in this research, 'Marabel' showed less browning incidence and color changes and, together with 'Agata', received the highest appearance score during storage at 5ºC. Vivaldi' and 'Agria' varieties showed intermediate potential in terms of storability and appearance, while 'Almera' was the less suitable to be used as fresh-cut. [*The above conclusion was drawn from the articles: "Suitability of five different potato cultivars (Solanum tuberosum L.) to be processed as fresh-cut products". Postharvest Biology and Technology 53 (2009) 138–144*].

3. ‘Marabel’ was characterized by low phenol content and PPO activity, and high antioxidant activity, which explained the lower susceptibility to browning. The high phenol content and high PAL activity, which is the key enzyme in phenolic synthesis, explained the susceptibility of ‘Vivaldi’, ‘Almera’ and ‘Agria’ to browning, even though ‘Almera’, also had high content in ascorbic acid and antioxidant activity [*The above conclusion was drawn from the article: “Suitability of five different potato cultivars (Solanum tuberosum L.) to be processed as fresh-cut products”. Postharvest Biology and Technology 53 (2009) 138–144*].

4. As for early potato cultivars (‘Ariana’, ‘Liseta’, ‘Safrane’ and ‘Spunta’) results indicated that ‘Safrane’ had the least color changes and browning incidence, received the highest appearance score during the first days of storage at both tested storage temperatures, and had a high ascorbic acid content and antioxidant activity; ‘Liseta’ and ‘Ariana’ showed intermediate potential in terms of storability and appearance, while ‘Spunta’ was the least suitable to be used as fresh-cut. [*The above conclusion was drawn from the article: “Suitability of 4 potato cultivars (Solanum tuberosum L.) to be processed as fresh-cut product. Early cultivars*. American Journal of Potato Research 88 *(2011) 403–411*].

5. In this study Vitamin C was correlated with a* value variation and appearance score during post-cutting storage: varieties with a higher total ascorbic acid content (‘Safrane’) also showed a lower Δa* value and a better appearance during storage, confirming the anti-browning activity of this compound. [*The above conclusion was drawn from the article: “Suitability of 4 potato cultivars (Solanum tuberosum L.) to be processed as fresh-cut product. Early cultivars*. American Journal of Potato Research 88 *(2011) 403–411*].

6. The study of quality evaluation and browning susceptibility of five artichoke cultivars (‘C3’, ‘Catanese’, ‘Tema’, ‘Violetto Foggiano’ and ‘Violetto Sardo’) for fresh-cut processing showed that cultivar ‘Catanese’ was the most suitable cultivar for processing as a fresh-cut product. [*The above conclusion was drawn from the article: “Screening quality and browning susceptibility of five artichoke cultivars for fresh-cut processing. Journal of the Science of Food and Agriculture 89 (2009) 2588–2594*].

7. ‘C3’ was the greatest source of phenol bioactive compounds, but the least suitable to be processed as a fresh-cut produce, due to the direct role of phenols as substrate of browning reactions. The cultivar ‘Catanese’ contained a significantly lower phenol content and was the most suitable cultivar to be processed as fresh-cut product. Despite its low phenol content, ‘Catanese’ showed an antioxidant activity comparable to ‘C3’, partially due to its high vitamin C content; thus, its nutritional value was also very significant. [*The above conclusion was drawn from the article: “Screening quality and browning susceptibility of five artichoke cultivars for fresh-cut processing. Journal of the Science of Food and Agriculture 89 (2009) 2588–2594*].

8. Also in this study the lower susceptibility to browning of ‘Catanese’ cultivar was attributed to a significantly low phenol content and a higher vitamin C content, confirming the role of phenols and the ascorbic acid in browning processes of fresh-cut products [*The above conclusion was drawn from the article: “Screening quality and browning susceptibility of five artichoke cultivars for fresh-cut processing. Journal of the Science of Food and Agriculture 89 (2009) 2588–2594*].

9. An algorithm for colour measurements of fresh-cut artichokes was developed, which can be used as support for laboratory experiments aimed to assess colour measurements on cut artichokes. This algorithm requiring little time for colour measurement and data recollection, reduced the risk of sample browning during colour acquisition. [*The above conclusion was drawn from the article: "Post-cutting quality changes of fresh-cut artichokes treated with different anti-browning agents as evaluated by image analysis". Postharvest Biology and Technology 62 (2011) 213–220*].

10. The image analysis algorithm, resulted to be very successful for the selection of an effective anti-browning treatment, supporting sensorial measurement [*The above conclusion was drawn from the article: "Post-cutting quality changes of fresh-cut artichokes treated with different anti-browning agents as evaluated by image analysis". Postharvest Biology and Technology 62 (2011) 213–220*].

11. The highest correlation of L* values measured on the whole quarter surface with appearance in fresh-cut artichokes suggested that the measurement of L* on whole quarters was more representative of the overall appearance of the cut artichokes as observed by the human eye. [*The above conclusion was drawn from the article: "Post-cutting quality changes of fresh-cut artichokes treated with different anti-browning agents as evaluated by image analysis". Postharvest Biology and Technology 62 (2011) 213–220*].

12. The screening among several anti-browning agents (ascorbic acid, citric acid, cysteine, and their combination, ethanol, sodium chloride, 4-hexylresorcino) made by sensorial evaluation and image analysis, showed that cysteine (0.5%) was the most effective treatment to prevent browning of fresh-cut artichokes and that its effectiveness was improved by increasing the pH of the solution from the natural pH (2.1) to pH 3. [*The above conclusion was drawn from the article: "Post-cutting quality changes of fresh-cut artichokes treated with different anti-browning agents as evaluated by image analysis". Postharvest Biology and Technology 62 (2011) 213–220*].

13. Colour and general appearance of fresh cut artichokes were affected by pH (from 2 to 7) of l-cysteine hydrochloride monohydrate pretreatment solutions. An increase of yellow colour was observed in all l-cysteine-treated artichokes, which was more visible at low pH values. In these conditions, a lower general appearance was also observed. [*The conclusion was drawn from the article: "Effect of solution pH of cysteine-based pre-treatments to prevent browning of fresh-cut artichokes". Postharvest Biology and Technology 75 (2013) 17–23*].

14. Results on PPO activity showed that after 1 days of storage PPO activity was lower in artichokes treated with cysteine solutions at lower pH values (2 and 3), followed by artichokes treated at pH 7, whereas starting from 3 days of storage a significant negative correlation was observed for PPO activity and pH, indicating that PPO activity decreased with the increase of the pH of the cysteine solution, resulting lower for artichokes treated with cysteine at pH 7 than for untreated samples. Since sulphites and thiol compounds act also as reducing agents at pH below 4, it was hypothesized that after 1 day in artichokes treated at pH 2 and 3, L-cysteine acted principally as reducing agent and that this effect was temporary, since the oxidation of cysteine is not reversible. With the increasing of the days of storage the reducing effect was exhausted and the thiol-group of L-cysteine was not so efficient in acidic conditions to form complexes with quinones and, therefore, to inhibit secondary oxidation and polymerization reactions as at higher pH values. These results may represent an important step in order to prevent browning of fresh-cut artichokes. [*The following conclusion has been drawn from the article: "Effect of solution pH of cysteine-based pre-treatments to prevent browning of fresh-cut artichokes". Postharvest Biology and Technology 75 (2013) 17–23*].

15. Post-cutting performance of potato cubes was influenced by cultivar, showing differences in terms of shelf-life of the untreated potato cubes. Moreover, potato cultivar pointed out different responses to the same anti-browning treatment as results. [*The following conclusion has been drawn from the article:* R*esponse of fresh-cut potato cubes of three different varieties to anti-browning treatments". Acta Horticulturae 876 (2010), 319-324*].

16. The optimization of whole fresh-cut process, including gas composition and packaging optimization, would constitute the next step in this research field [*The above conclusion was drawn from the articles: "Suitability of five different potato cultivars (Solanum tuberosum L.) to be processed as fresh-cut products". Postharvest Biology and Technology 53 (2009) 138–144; "Suitability of 4 potato cultivars (Solanum tuberosum L.) to be processed as fresh-cut product. Early cultivars*. American *Journal of Potato Research 88 (2011) 403–411; "Screening quality and browning susceptibility of five artichoke cultivars for fresh-cut processing. Journal of the Science of Food and Agriculture 89 (2009) 2588–2594*].

Capítulo 8

Capítulo 8. BIBLIOGRAFÍA

Agamia, E.H. 1984. Effect of some postharvest treatments on artichoke heads. Beitr Trop Landwirtsch Veterinarmed 22, 95–100.

Ahvenainen, R. 1996. New approaches in improving the shelf life of minimally processed fruit and vegetables. Trends Food Science Technology 7, 179–186.

Alamanni, M.C., Cossu, M. 2003. Antioxidant activity of the extracts of the edible part of artichoke (*Cynara scolymus* L.) var. spinoso sardo. Italian Journal of Food Science 15, 187–195.

Alonso-Arce, F. 2008. El Cultivo de la Patata. Mundi-Prensa, Madrid, España.

Amodio, M.L., Rinaldi, R., Colelli, G. 2006. Influence of atmosphere composition on quality attributes of ready-to- cook fresh-cut vegetable soup. Acta Horticulturae. (ISHS) 712, 677-684.

Amodio, M.L., Cabezas-Serrano, A.B., Rinaldi, R. Colelli, G. 2007. Implementation of rating scales for visual quality evaluation of various vegetable crops. In: Kader, A.A., Cantwell, M. (Eds.), Produce Quality Rating Scales and Colour Charts, Appendix 1, Postharvest Horticulture Series NO. 23. University of California, Davis.

Angós, I., Vírseda, P., Fernández, T. 2008. Control of respiration and color modification on minimally processed potatoes by means of low and high O_2/CO_2 atmospheres. Postharvest Biology and Technology 48, 422-430.

Arvanitoyannis, I.S., Vaitsi, O., Mavromatis, A. 2008. Potato: A comparative study of the effect of cultivars and cultivation conditions and genetic modification on the physico-chemical properties of potato tubers in conjunction with multivariate analysis towards authenticity. Critical Reviews in Food Science and Nutrition 48, 799-823.

Aubert, S., Foury, C. 1981. Couleur et pigmentation antohicyanique de l'artichaut (*Cynara scolymus* L). In: Marzi, V., Lattanzio, V. (Eds.), Studi sul Carciofo. Industrie Grafiche Laterza, Bari, Italia, pp. 57–76.

Augustin, J. 1975. Variation in the nutritional composition of fresh potatoes. Journal of Food Science 40, 1295-1299.

Beverly, R.B., Latimer, J.G., Smittle, D.A. 1993. Preharvest physiological and cultural effects on postharvest quality. In: Florkowski, W.J., Prussia, S.E., Shewfelt,

R.L., Brueckner, B. (Eds.), Postharvest Handling: A Systems Approach. Academic Press, New York, NY, USA, pp. 73–98.

Bianco, V.V. 1990. Carciofo *(Cynara scolymus L.).* In: Bianco, V., Pimpini F. (Eds.), Orticoltura. Pàtron Editore, Bologna, Italia, pp. 209–240.

BOE. 1983. Orden de 6 de julio de 1983 por la que se aprueba la norma de calidad para patata de consumo destinada al mercado interior (modificada por Orden de 29 de octubre de 1986). BOE núm.166 de 13 de julio de 1983, páginas 19546 a 19547.

Bolin, H.R., Huxsoll, C.C. 1991. Effect of preparation and storage parameters on quality retention of salad-cut lettuce. Journal of Food Science 56, 60–67.

Brecht, J.K. 1995. Physiology of lightly processed fruits and vegetables. HortScience 30, 18–22.

Brosnan, T., Sun, D. 2002. Inspection and grading of agricultural and food products by computer vision systems – a review. Computers and Electronics in Agriculture 36, 193–213.

Brosnan, T., Sun, D.W. 2004. Improving quality inspection of food products by computer vision – a review. Journal of Food Engineering 61, 3–16.

Bruhn, C. 1995. Consumer perception of quality. In: Singh R.P., Oliveira, F.A.R. (Eds.), Minimal Processing of Foods and Process Optimization. An Interface. CRC Press, Boca Ration, Florida, USA, pp. 493–504.

Burton, W.G. 1966. The Potato. A Survey of Its History and of the Factors Influencing Its Yield, Nutritive Value, Quality and Storage. European Association of Potato Research, Wageningen, The Netherlands.

Burton, W.G. 1982. Post-Harvest Physiology of Food Crops. Longman, New York, NY, USA.

Burton,W.G. 1989. The Potato, 3rd ed. Longman Scientific & Technical, Essex, England.

Buta, J.G., Moline, H.E. 2001. Prevention of browning of potato slices using polyphenoloxidase inhibitors and organic acids. Journal of Food Quality 24, 271–282.

Cannella, C. 2009. In: Calabrese N., (Eds.), Il Carciofo e il Cardo. Collana Coltura & Cultura, Aspetti nutrizionali. Bologna, Italy, pp. 46-49.

Cantos, E., Tudela, J.A., Gil, M.I., Espín, J.C. 2002. Phenolic compounds and related enzymes are not rate-limiting in browning development of fresh-cut potatoes. Journal of Agricultural and Food Chemistry 50, 3015–3023.

Carman, A.S., Kuan, S.S., George, M.W., Francis, O.J., Kirschenheuter, G.P. 1986. Rapid high-performance liquid chromatographic determination of the potato glycoalkaloids α-solanine and α-chaconine. Journal of Agricultural and Food Chemistry 34, 279–282.

Carpita, N.C., Keller, F., Gibeaut, D.M., Housley, T.L., Matile, P. 1991. Syntesis of inulin oligomers in tissue slices, protoplasts and intact vacuoles of Jerusalem artichoke. Journal of Plant Physiology 138, 204–210.

Castañer, M., Gil, M.I., Artés, F., Tomás-Barbenán, F.A. 1996. Inhibition of browning of harvested head lettuce. Journal of Food Science, 61, 314–316.

Chalom, S., Elrezzi, E., Pena, P., Astiarsaran, I., Bello, J. 1995. Composition of sulfited potatoes: comparison with fresh and frozen potatoes. Plant Foods for Human Nutrition 47, 133-138.

Chen, K., Sun, X., Qin, Ch., Tang, X. 2010. Colour grading of beef fat by using computer vision and support vector machine. Computers and Electronics in Agriculture 70, 27–32.

Cherry, J.H., Singh, S.S. 1990. Discoloration preventing food preservative and method. Patent number: 4937085.

Colelli, G., Calabrese, N., 2009. Trasformazione industriale. In: Calabrese N. (Ed.), Il Carciofo e il Cardo. Collana Coltura & Cultura, Edizioni Script, Bologna, Italy, pp. 348-355.

D'Amato, D., Campaniello, D., Corbo, M.R., Marchionni, R., Sinigaglia, M. 2002. Determinazione della shelf-life e caratterizzazione microbiologica di pesche e fragole minimamente trattate. Atti del CISETA. 5° Congresso Italiano di Scienza e Tecnologia degli Alimenti. Cernobbio, Italia, 13-14 settembre 2001, pp. 123–131.

Darwen, C.W., John, P. 1989. Localization of the enzymes of fructan metabolism in vacuoles isolated by a mechanical method from tubers of Jerusalem artichoke (*Helianthus tuberosus* L.). Plant Physiology 89, 658–663.

Davey, M.W., Montagu, M.V., Inze, D., Sanmartin, M., Kanellis, A., Smirnoff, N.; Benzie, I.J.J., Strain, J.J., Favell, D., Fletcher, J. 2000, Plant L-ascorbic acid: chemistry, function, metabolism, bioavailability and effects of processing. Journal Science Food Agriculture 80, 825-860.

Degl'Innocenti, E., Guidi, L., Paradossi, A., Tognoni, F. 2005. Biochemical study of leaf browning in minimally processed leaves of lettuce (*Lactuca sativa* L. var. acephala). Journal of Agricultural and Food Chemistry 53, 9980–9984.

Del Nobile, M.A., Conte, A., Scrocco, C., Laverse, J., Brescia, I., Conversa, G., Elia, A. 2009. New packaging strategies to preserve fresh-cut artichoke quality during refrigerated storage. Innovative Food Science and Emerging Technology 10, 128–133.

Dellacecca, V., Magnifico, V., Marzi, V., Porceddu, E., Scarascia-Mugnozza, G.T. 1976. Contributo alla conoscenza delle varietà di carciofo coltivate nel mondo. 2° Congresso Internazionale Carciofo. Bari, Italia. Minerva Medica, Torino, Italia, 199–316.

Dennis, J.A.B. 1993. The effects of selected antibrowning agents, selected packaging methods, and storage time on some characteristics of sliced raw potatoes. Dissertation, Oklahoma State University, Stillwater, USA.

Di Venere, D., Maiani, G., Miccadei, S. 2009. Composti bioattivi. In: Calabrese, N., (Eds), Il Carciofo e il Cardo. Collana Coltura & Cultura. Edizioni Script, Bologna, Italy, pp. 60-69.

Di Venere, D., Linsalata, V., Calabrese, N., Cardinali, A., Sergio, L. 2005. Biochemical characterization of wild and cultivated cardoon accessions. Acta Horticolturae 681, 523–528.

Dorantes-Álvarez, L., Parada-Dorantes, L., Ortiz-Moreno, A., Santiago-Pineda, A., Chiral-Boix, S., Barbosa Cánovas, G. 1998. Effect of anti-browning compounds on the quality of minimally processed avocados. Food Science and Technology International 4, 107–113.

Drake, S.R., Spayd, S.E. 1983. Influence of calcium treatment on 'Golden Delicious' apple quality. Journal of Food Science 48, 403–405.

Dunford, H.B., Stillman, J.S. 1976. On the function and mechanism of action of peroxidases. Coordination Chemistry Reviews 19, 187–251.

Eidhin, D.M., Murphy, E., O'Beirne, D. 2005. Polyphenoloxidase from apple (*Malus domestica* Borkh. cv. Bramley's seedling): purification strategies and characterization. Journal of Food Science 7, 51–58.

Erbil, H.Y., Muftugil, N. 1986. Lengthening the postharvest life of peaches by coating with hydrophobic emulsions. Journal of Food Processing and Preservation 10, 269–279.

Espín, J.C., Ochoa, M., Tudela, J., García-Cánovas, F. 1997. Monophenolase activity of strawberry polyphenol oxidase. Phytochemistry 45, 667–670.

FAOSTAT, 2012. Producción de cultivos primarios. Food and Agricultural Organization of the United Nations. Agricultural Bulletin Board on Data Collection, Dissemination and Quality of Statistics. Última actualización: Agosto 2012. Dirección URL: http://faostat.fao.org/DesktopDefault.aspx?PageID=567&lang=es#ancor [Consulta: 4 de Diciembre 2012]

FEPEX, 2009. Federación Española de Asociaciones de Productores Exportadores de Frutas, Hortalizas, Flores y Plantas Vivas. Última actualización Datos del sector. Dirección URL http://www.fepex.es/publico/datosSector/DatosSector.aspx [Consulta: 20 de Noviembre 2012].

Ferreira, F., Moyna, P., Soule, S., Vázquez, A. 1993. Rapid determination of Solanum glycoalkaloids by thin-layer chromatographic scanning. Journal of Chromatography A 653, 380–384.

Fonseca, S.C., Oliveira, F.A.R., Brecht J.K. 2002. Modelling respiration rate of fresh fruits and vegetables for modified atmosphere packages: a review. Journal of Food Engineering 52, 99–119.

Fratianni, F., Tucci, M., De Palma, M., Pepe, R., Nazzaro, F. 2007. Polyphenolic composition in different parts of some cultivars of globe artichoke (*Cynara cardunculus* L. var. *scolymus* (L.) Fiori). Food Chemistry 104, 1282–1286.

Frehner, M., Keller, F., Wiemken, A. 1984. Localization of fructan metabolism in the vacuoles isolated from protoplasts of Jerusalem artichoke tubers (*Helianthus tuberosus* L.). Journal of Plant Physiology 116, 197–208.

Friedman, M., Bautista, F.F. 1995. Inhibition of polyphenol oxidase by thiols in the absence and presence of potato tissue suspensions. Journal Agriculture and Food Chemestry 43, 69–76.

Friedman, M., McDonald, G. 1997. Potato glycoalkaloids: chemistry, analysis, safety and plant physiology. Critical Reviews in Plant Sciences 16, 55–132.

Galdón, B.R., Rodríguez, L.H., Mesa, D.R., León, H.L., Pérez, N.L., Rodríguez, E.M., Romero, C.D. 2012. Differentiation of potato cultivars experimentally cultivated based on their chemical composition and by applying linear discriminant analysis. Food Chemistry 133, 1241-1248.

García, E.L., Barrett, D.M. 2002. Preservative treatments for fresh-cut fruits and vegetables. In: Lamikanra, O. (Ed.), Fresh-Cut Fruits and Vegetables. Science, Technology and Market. CRC Press, Boca Raton, Florida, USA, pp. 267–303.

Gardner, J., Manohar, S., Borisenok, W.S. 1991. Sulfite-free preservative for fresh peeled fruits and vegetables. Patent number: 4988523.

Gil-Ortega, R. 1999 El Cultivo de la Alcachofa. Variedades de semilla. Hoja Divulgadora 2097 HD. Ministerio de Agricultura, Pesca y Alimentación, Madrid, España.

Gil-Ortega, R. 2001. Alcachofa. En: Nuez, F., Llacer, G. (Eds.), La Horticultura Española. Sociedad Española de Ciencias Hortícolas (SECH) y Ediciones de Horticultura, S.L., Madrid, España, pp 90–92.

Giménez, M., Olarte, C., Sanz, S., Lomas, C., Echávarri, J.F., Ayala, F. 2003. Relation between spoilage and microbiological quality in minimally processed artichoke packaged with different films. Food Microbiology 20, 231–242.

Golan-Goldhrish, A., Osuga, D.T., Chen, A.O., Whitaker, J.R. 1992. Effect of ascorbic acid and copper on proteins. In: O'Souza, V.T., Feder, J. (Eds.), The Bioorganic Chemistry of Enzymatic Catalysis: an homage to Myron L. Bender. CRC Press, Boca Raton, Florida, USA, pp 61–76.

González, H. 2000. Producción de patatas: consideraciones sobre su cultivo y conservación, Revista Patatas 5, 70-74.

Gorny, J.R., Hess-Pierce, B., Kader A.A. 1998. Effect of fruit ripeness and Storage temperature on the deterioration rate of fresh-cut peach and nectarine slices. Hortscience 33, 110–113.

Gorny, J.R., Hess-Pierce, B., Kader A.A. 1999. Quality changes in fresh-cut peach and nectarine slices as affected by cultivar, storage atmosphere and chemical treaments. Journal of Food Science 64, 429–432.

Gorny, J.R., Cifuentes, R.A., Hess-Pierce, B.H., Kader, A.A. 2000. Quality changes infresh-cut pear slices as affected by cultivar, ripeness stage, fruit size and storage regime. Journal of Food Science 65, 541–544.

Gorny, J.R., Hess-Pierce, B., Cifuentes, R.A., Kader, A.A. 2002. Quality changes in freshcut pear slices as effected by controlled atmosphere and chemical preservatives. Postharvest Biology and Technology 24, 271–278.

Gray, D., Hughes J.C. 1978. Tuber potato quality. In: Harris, P.M. (Eds.), The Potato Crop – The Scientific Basis For Improvement. Chapman and Hall, London, UK, pp. 504–544.

Gregory, J.F.I. 1996, Vitamins. In: Fennema, O.R. (Ed.), Food Chemistry. Dekker, New York, NY, USA, pp. 559-568.

Guerrero-Beltrán, J.A., Swanson, B.G., Barbosa-Cánovas, G.V. 2005. Inhibition of polyphenoloxidase in mango puree with 4-hexylresorcinol, cysteine and ascorbic acid. Lebensmittel-Wissenschaft & Technologie 38, 625–630.

Gunasekaran, S. 1996. Computer vision technology for food quality assurance. Trends in Food Science and Technology 7, 245–255.

Gunes, G., Lee, C.Y. 1997. Color of minimally processed potatoes as affected by modified atmosphere packaging and antibrowning agents. Journal of Food Science 62, 572–578.

Hasegawa, D., Johnson, R.M., Gould, W.A. 1966. Effect of cold storage on chlorogenic acid content of potatoes. Journal of Agricultural and Food Chemistry 14, 165-169.

Hellwege, E.M., Raap, M., Gritscher, D., Willmitzer, L., Heyer, A.G. 1998. Differences in chain length distribution of inulin from *Cynara scolymus* and *Helianthus tuberosus* are reflected in a transient plant expression system using the respective 1-FFT cDNAs. FEBS Letters 427, 25–28.

Hellwege, E.M., Czapla, S., Jahnke, A., Willmitzer, L., Heyer, A.G. 2000. Transgenic potato (*Solanum tuberosum*) tubers synthesize the full spectrum of inulin molecules naturally occurring in globe artichoke (*Cynara scolymus*) roots. Proceedings of the National Academy of Sciences 97, pp. 8699–8704.

Hlywka, J.J., Stephenson, G.R., Sears, M.K., Rickey, Y.Y. 1994. Effect of insect damage on glycoalkaloid content in potatoes (*Solanum tuberosum*). Journal of Agricultural and Food Chemistry 42, 2545–2550.

Hopfinger, J.A., Poovaiah, B.W., Petterson, M.E. 1984. Calcium and magnesium interactions in browning of "Golden Delicious" apples with bitter pit. Scientia Horticulturae 23, 345–351.

Hornig, D.H., Moser, U., Glathaar, B.E. 1988. Ascorbic acid. In: Shils, M.E., Young, V.R., (Eds.), Modern Nutrition in Health and Disease. Lea and Febiger: Philadelphia, PA, USA, pp. 417- 435.

Hurrell, R.F., Finot, P.A.N. 1984. Nutritional consequences of the reactions between proteins and oxidized polyphenols. In: Friedman, M. (Ed.), Nutritional and Toxicological Aspects of Food Safety. Plenum: New York, USA, pp. 423–435.

Hutchings, J.B. 1999. Food Color and Appearance. Aspen Publishers Inc., New York, NY, USA.

Hyodo, H., Fujinami, H. 1989. The effect of 2,5-norbornadiene on the induction of activity of phenylalanine ammonia-lyase in wounded mesocarp tissue of Cucurbita maxima. Plant Cell and Physiology 30, 857–860.

Illescas, J.L, Bacho, O., 2005. Análisis de las principales variedades de hortalizas y patatas. Distribución y Consumo Septiembre-Octubre, 29–105.

Jackman, P., Sun, D., Allen, P. 2009. Automatic segmentation of beef *longissimus dorsi* muscle and marbling by an adaptable algorithm. Meat Science 83, 187–194.

Janovitz-Klapp, A., Richard, F., Nicolas, J. 1989. Polyphenol oxidase from apple. Partial purification and some properties. Phytochemistry 28, 2903–2097.

Jay, M.J. 1992. Modern Food Microbiology, 6th edit. New York: Van Nostrand Reinhold. López, A. 1997. Complete Course in Canning, 12th edit., Vol. III.Baltimore: The Canning Trade.

Kaaber, L., Martinsen, B.K., Bråthen, E., Shomer, I. 2002. Browning inhibition and textural changes of pre-peeled potatoes caused by anaerobic conditions.LWT - Food Science and Technology 35, 526–531.

Kader, A.A. 1990. The effect of storage methods on the quality of fresh-horticultural crops. In: Baronio, P., Pratella, G.C., Baldassarri, N. (Eds.), Qualità Dei Prodotti Ortofrutticoli Postraccolta. Fondazione Cesena Agricoltura, Cesena, pp. 11-26

Kader, A.A. 2002. Postharvest biology and technology: An overwiew. In: Kader, A.A. (Ed). Postharvest Technology of Horticultural Crops, Pub. 3311, Oakland, CA, USA, pp. 39-47.

Kader, A.A., Cantwell, M. (Eds.). 2004. Produce Quality Rating Scales and Color Charts. University of California Postharvest Horticulture Series No. 23, Davis, CA, USA.

Ke, D., Saltveit, M.E. 1986. Effects of calcium and auxin on russet spotting and phenylalanine ammonia-lyase activity in iceberg lettuce. Horticulture 21, 1169–1171.

Kenigsbuch, D., Chalupowicz, D., Aharon, Z., Maurer, D., Aharoni, N. 2007. The effect of CO_2 and 1-methylcyclopropene on the regulation of postharvest senescence of mint, *Mentha longifolia* L. Postharvest Biology and Technology 43 165–173.

Kim, Y.J., Uyama, H. 2005. Tyrosinase inhibitors from natural and synthetic sources: Structure, inhibition mechanism and perspective for the future. Cellular and Molecular Life Sciences, 62, 1707–1723.

King, A.D., Bolin H.R. 1989. Physiological and microbiological storage stability of minimally processed fruits and vegetables. Food Technology 43, 132–135.

La Zazzera, M. 2011. Management of Gas Composition for Fresh-Cut Artichokes *(Cynara scolymus L.)*. PhD Thesis. Università di Foggia, Facoltà di Agraria, Foggia, Italia.

La Zazzera, M., Rinaldi, R., Amodio, M.L., Colelli, G. 2012. Influence of high CO_2 atmosphere composition on fresh-cut artichoke quality attributes. Acta Horticulturae 934, 633–640.

Lachman, J., Hamouz, K. 2005. Red and purple coloured potatoes as significant antioxidant source in human nutritions A review. *Plant Soil En*V*iron. 51*, 477–482.

Lambrecht, H.S. 1995. Sulfite substitutes for the prevention of enzymatic browning in foods. In Lee, C.Y., Whitaker, J.R. (Eds.), Enzymatic Browning and its Prevention. American Chemical Society, Washington, D.C., USA, pp. 313–323.

Larrigaudière, C., Ubach, D., Soria, Y., Rojas-Graü, M.A., Martin-Belloso, O. 2008. Oxidative behavior of fresh-cut 'Fuji' apples treated with stabilising substances. Journal of Food Science 88, 1770–1776.

Lattanzio, V. 1982. Composizione, valore nutritivo e terapeutico del carciofo. Informatore Agrario, XXXVIII 1, 18727–18731.

Lattanzio, V. 2003. Bioactive polyphenols: their role in quality and storability of fruit and vegetables. Journal of Applied Botany 77, 128-146.

Lattanzio, V., Van Sumere, C.F. 1987. Changes in phenolic compounds during the development and cold storage of artichoke (*Cynara scolymus* L.) heads. Food Chemistry 24, 37–50.

Lattanzio, V., Kroon P.A., Linsalata, V., Cardinali, A. 2009. Globe artichoke: a functional food and source of nutraceutical ingredients. Journal of Functional Foods 1, 131-144.

Lattanzio, V., Linsalata, V., Palmieri, S., Van Sumere, C.F. 1989. The beneficial effect of citric and ascorbic acid on the phenolic browning reaction in stored artichoke (*Cynara scolymus* L.) heads. Food Chemistry 33, pp. 93–106.

Lattanzio, V., Cardinali, A., Di Venere, D., Linsalata, V., Palmieri, S. 1994. Browning phenomena in stored artichoke (*Cynara scolymus* L.) heads: enzymic or chemical reaction? Food Chemestry 50, 1–7.

Laurila, E., Kervinen, R., Ahvenainen, R. 1998. The inhibition of enzymatic browning in minimally processed vegetables and fruits. Postharvest News and Information 9, 53–66.

León, K., Mery, D., Pedreschi, F., León, J. 2006. Color measurement in L *a *b * units from RGB digital images. Food Research International 39, 1084–1091.

Leroy, G., Grongnet, J.F., Mabeau, S., Le Corre, D., Baty-Julien, C. 2010. Changes in inulin and soluble sugar concentration in artichokes (*Cynara scolymus* L.) during storage. Jorunal of Science and Food Agriculture 90, 1203-1209.

Lewis, C., Walker, J., Lancaster, J., Sutton, K. 1998, Determination of anthocyanins, flavonoids and phenolic acids in potatoes. I: Coloured cultivars of Solanum tuberosum L. Jorunal of Science and Food Agriculture 77, 45–57.

Limbo, S., Piergiovanni, L. 2007. Minimally processed potatoes Part 2. Effect of high oxygen partial pressures in combination with ascorbic and citric on loss of some quality traits. Postharvest Biology and Thechnology 43, 221–229.

Lipton, W.J., Stewart, J.K. 1963. Effects of precooling on market quality of globe artichokes. Marketing. Research Rpt. No. 633. USDA, USA.

Llorach, R., Espin, J.C., Tomas-Barneran, F.A., Ferreres, F. 2002. Artichoke (*Cynara scolymus* L.) by products as a potential source of health promoting antioxidant phenolics. Journal of Agriculture and Food Chemistry 50, 3458–3464.

Lombardo, S., Pandino, G., Mauromicale, G., Knödler, M., Carle, R., Schieber, A. 2010 Influence of genotype, harvest time and plant part on polyphenolic compositionof globe artichoke [*Cynara cardunculus* L. var. *scolymus* (L.) Fiori] Food Chemistry 119, 1175–1181.

López-Gálvez, G., Saltveit, M., Cantwell, M. 1996. Wound-induced phenylalanine ammonia lyase activity: factors affecting its induction and correlation with the quality of minimally processed lettuces. Postharvest Biology and Technology 9, 223–233.

Macua, J.I., 1995. Colección de variedades de alcachofa. Agrícola Vergel 14, 491–496.

Macua, J.I., Malumbres, A., Lahoz, I. 2003. La alcachofa en Navarra. Navarra Agraria, 137, 13–17.

MAGRAMA (Ministerio de Agricultura, Alimentación y Medio Ambiente). 2011. Anuario de Estadística Agroalimentaria. Ministerio de Agricultura Alimentación y Medio Ambiente. Madrid, España.

Marangoni, A.G., Palma, T., Stanley, D.W. 1996. Membrane effects in postharvest physiology. Postharvest Biology and Technology 7, 193–217.

Martínez, J.A., Carbonell, M. 2009. Estudio comparativo de cultivares de alcachofa de propagación sexual o vegetativa. En: Martín-Trujillo, M., Gázquez-Garrido, J.C., Hoyos-Echevarría, P., Muñoz-Odina, P. (Eds.), XXXVII Seminario de Técnicos y Especialistas en Horticultura. Almería, 2007. Ministerio de Medio Ambiente y Medio Rural y Marino, Centro de Publicaciones, Madrid, España, pp. 153–162.

Martínez, M.V., Whitaker, J.R. 1995. The biochemistry and control of enzymatic browning. Food Science and Technology 6, 195–200.

Massantini, R., Carlini, P., Mencarelli, F. 2000. Fisiologia e tecnologia post-raccolta delle albicocche come prodotti della IV gamma. Industrie Alimentari 39, 162–168.

Massignan, L., Lovino, R., De Cillis, M.F., Di Venere, D., Linsalata, V., Bianco V.V. 2005. Effect of harvest time, processing and packaging on the quality of "ready to use artichokes". Acta Horticulturae 681, 629–636.

Mateos, M., Ke, D., Cantwell, M., Kader, A.A. 1993. Phenolic metabolism and ethanolic fermentation of intact and cut lettuce exposed to CO_2-enriched atmospheres. Postharvest Biology and Technology 3, 225–233.

Matheis, G., Belitz, H.D. 1977. Studies on enzymic browning of potatoes (*Solanum tuberosum*) II. Quantitative relationship between browning and its causative factors. Z Lebensm Unters Forsch 163, 186–190.

Matheis, G., Whitaker, J.R. 1984. Modification of proteins by polyphenol oxidase and peroxidase and their products. Journal of Food Biochemistry 8, 137–162.

Mayer, A., Harel, E., 1991. Phenoloxidases and their significance in fruit and vegetable. In: Fox, P.F. (Ed.), Food Enzymology, vol. 1. Elsevier, London, UK, pp. 373–398.

McCay, C.M., McCay, J.B., Smith, O. 1975. The nutritive value of potatoes. In: Talburt, W.F., Smith, O. (Eds.), Potato. Processing AVI Publishing, Westport, CT, USA.

McEvily, A., Iyengar, R., Otwell, S. 1992. Inhibition of enzymic browning in foods and beverages. Critical Review in Food Science and Nutrition 32, 253–273.

McEvily, A.J., Iyengar, R., Otwell, S. 1991. Sulfite alternative prevents shrimp melanosis. Food Technology 45, 80–86.

Mitcham, B., Cantwell, M., Kader, A.A. 1996. Methods for determining quality of fresh commodities. Perishables Handling Newsletter 85, 1–5.

Molnar-Perl, I., Friedman, M. 1990. Inhibition of browning by sulfur amino acids. 3. Apples and potatoes. Journal Agriculture and Food Chemistry 38, 1652–1658.

Mondy, N.I. 2000. Factor affecting the nutritional quality of potatoes. In: Hooker, W.J. (Eds.), Procceding International Congress- Research for the Potato in the Year 2000. International Potato Centre, pp. 136-139.

Monje, M. 2012. IV Gama: El valor de una marca. Alimarket 262, 95–106.

Nicolas, J.J., Richard-Forget, F.C., Goupy, P.M., Amiot, M.J., Aubert, S.Y. 1994. Enzymatic browning reactions in apple and apple products. Critical Reviews in Food Science and Nutrition 34, 109–157.

Nourian, F., Ramaswamya, H.S., Kushalappab, A.C. 2003. Kinetics of quality change associated with potatoes stored at different temperatures. Lebensmittel-Wissenschaft und -Technologie 36 49–65.

Orlovskaya, T. V., Luneva, I. L., Chelombit'ko, V. A. 2007. Chemical composition of Cynara scolymus leaves. Chemistry of Natural Compounds, 43, 239–240.

O'Sullivan, M.G., Byrne, D.V., Martens, H., Gidskehaug, L.H., Andersen, H.J., Martens, M. 2003. Evaluation of pork colour: prediction of visual sensory quality of meat from instrumental and computer vision methods of colour analysis. Meat Science 65, 909–918.

Özoglu, H., Bayindirli, A. 2002. Inhibition of enzymatic browning in cloudy apple juice with selected antibrowning agents. Food Control 13, 213–221.

Pérez-Trejo, M.S., Janes, H.W., Frenkel, C. 1981. Mobilization of respiratory metabolism in potato tubers by carbon dioxide. Plant Physiology 67, 514–517.

Peri, G., Romaniello, R., Colelli, G., Amodio, M.L. 2005. Misurazione della qualità dei prodotti orticoli in foglia mediante analisi d'immagine. Atti Conv. AIIA2005

"L'Ingegneria Agraria per lo Sviluppo Sostenibile dell'Area Mediterranea", Catania. Codice lavoro 7020.

Peroni, D. G., Boner, A.L. 1995. Sulfite sensitivity. Clinical & Experimental Allergy 25, 680-681.

Pollock, C.J. 1986. Fructans and the metabolism of sucrose in vascular plants. New Phytologist 104, 1-24.

Pontis, H. G., 1990. Fructans. In: Dey, P.M., Harborne, J.B. (Eds.), Methods in Plant Biochemistry. Academic Press, London, UK, pp. 353-369.

Prota, G. 1988. Progress in the chemistry of melanin and related metabolites. Medicinal Research Reviews, 8, 525–556.

Racchi, M., Daglia, M., Lanni, C., Papetti, A., Govoni, S., Gazzani, G. 2002. Antiradical activity of water soluble components in common diet vegetables. Journal of Agricultural and Food Chemistry 50, 1272-1277.

Rapaille, A., Gonze, M., Vanderschueren, F. 1995. Formulating sugar-free chocolate products with maltitol. Food Technology 49, 51–54.

Reeve, R. M., Hautala, E., Weaver, M.L. 1969. Anatomy and compositional variation within the potatoes. 2. Phenolics, enzymes and other minor components. American Potato Journal 46, 374-386.

Ricci, I. 2012. Influence of Pre-Cutting Operations on Quality of Fresh-Cut Artichokes. (*Cynara scolymus L.*). PhD Thesis. Università di Foggia, Facoltà di Agraria, Foggia, Italia.

Rice-Evans, C.A. y Miller, N.J., 1996. Antioxidant activities of flavonoide as bioactive components of food. Biochemical Society Transactions, 24 790-795.

Richard-Forget, F.C., Goupy, P.M., Nicolas, J.J. 1992. Cysteine as an inhibitor of enzymatic browning. 2. Kinetic studies. Journal of Agricultural and Food Chemistry 40, 2108–2113.

Richardson, T., Hyslop, D.B. 1985. Enzymes. In: Fennema, O.R. (Ed.), Food Chemistry, 2nd ed. Marcel Dekker, New York, NY, USA, pp. 371–476.

Ritenour, M.A., Ahrens, M.J., Saltveit, M.E. 1995. Effects of temperature on ethylene-induced phenylalanine ammonia lyase activity and russet spotting in harvested iceberg lettuce. Journal of American Society of Horticultural Science 120, 84–87.

Riva, M., 2003. Approfondimenti: il colore e la sua misurazione. Info Sheet n. 15-03/07/03 DISTAM, Università di Milano. Available: www.distam.unimi.it

Roberfroid, M.B., Delzenne, N.M. 1998. Dietary fructans. Annual Review of Nutrition 18, 117–143.

Rocculi, P., Gómez-Galindo, F., Mendoza, F., Wadsö, L., Romani, S., Dalla Rosa, M., Sjöholm, I. 2007. Effects of the application of anti-browning substances on the metabolic activity and sugar composition of fresh-cut potatoes. Postharvest Biology and Technology 43, 151–157.

Rodríguez-Saona, L.E., Giusti, M.M., Wrolstad, R.E. 1998. Anthocyaninpigment composition of red-fleshed potatoes. Journal of Food Science 63, 458–465.

Rodríguez-Saona, L.E., Wrolstad, R.E., Pereira, C. 1999. Glycoalkaloid content and anthocyanin stability to alkaline treatment of red-fleshed potato extracts. Journal of Food Science 64, 445–450.

Rojas-Graü, M.A., Sobrino-López, A., Tapia, M.S., Martin-Belloso, O. 2006. Browning inhibition in fresh-cut 'Fuji' Apple slice by natural antibrowning agent. Journal of Food Science 71, 59–65.

Romani, A., Pinelli, P., Cantini, C., Cimato, C., Heimler, D., 2006. Characterization of Violetto di Toscana, a typical Italian variety of artichoke (*Cynara scolymus* L.). Food Chemistry 95, 221–225.

Rosen, J.C., Kader, A.A. 1989. Postharvest physiology and quality maintenance of sliced pear and strawberry fruits. Journal of Food Science 54, 656–659.

Ryall, A.L., Lipton, W.J. 1979. Handling, Transportation and Storage of Fruits and Vgetables. Vol. 1. Vegetables and Melons. AVI, Westport, CT, USA.

Sala, F., Carpintero, C. (Eds.). 1967. La Alcachofa. Ministerio de Agricultura Ministerio de Agricultura, Pesca y Alimentación. Centro de Publicaciones 978-84-500-0190-7, Madrid, España.

Saltveit, M.E. 1989. Effect of alcohols and their interaction with ethylene on the ripening of epidermal pericarp discs of tomato fruit. Plant Physiololgy 90, 167–174.

Saltveit, M.E., 1991. Artichoke. In: Lidster, P., Blanpied, G., Prange, R. (Eds.), Controlled-Atmposphere Disorders of Cmmercial Fruits and Vegetables. Pub. 1847/E. Ag. Ottawa Ontario, Canada, pp. 23-24.

Saltveit, M.E. 1997. Physical and physiological changes in minimally processed fruits and vegetables. In: Tomás-Barberan, F.A., Robins, R.J. (Eds.), Phytochemistry of Fruits and Vegetables. Clarendon Press, Oxford, UK, pp. 205–220.

Salunkhe, D. K., Jadhav S.J., Kadam S.S., 1991. Potato: Production, Processing and Products CRC Press, Boca Raton, FL.,USA.

Sánchez, M.T. 2003. Procesos de Elaboración de Alimentos y Bebidas. Mundi-Prensa, Madrid, España.

Sánchez, M.T. 2004. Procesos de Conservación Poscosecha de Productos Vegetales. A. Madrid Vicente, Madrid, España.

Sanderson, J.B., White, P.R. 1982. Effect off in-row spacing on potato tuber yield, sizes and numbers measured at 10 weekly sampling dates. American Potato Journal 59, 484–492.

Sapers, G.M., Miller, R.L. 1992. Enzymatic browning control in potato with ascorbic acid-2-phosphates. Journal of Food Science, 57, 1132–1135.

Sapers, G.M., Miller, R.L. 1998. Browning inhibition in fresh-cut pears. Journal of Food Science 63, 342–346.

Sapers, G.M., Cooke, P.H., Heidel, A.E., Martin, S.T., Miller R.L. 1997. Structural changes related to texture of pre-peeled potatoes. Journal of Food Science 62, 797–803.

Sapers, G.M., Miller, R.L., Miller, F.C., Cooke, P.H., Choi, S.W. 1994. Enzymatic browning control in minimally processed mushrooms. Journal of Food Science, 59, 1042–1047.

Schütz, K., Kammerer, D., Carle, R., Schieber, A. 2004. Identification and quantification of caffeoylquinic acids and flavonoids from artichoke (*Cynara scolymus* L.) heads, juice, and pomace by HPLC-DAD-ESI/MS^n. Journal of Agricultural and Food Chemistry 52, 4090–4096.

Schwimmer, S., Vevenue, A., Western, W., Potter, A. 1954. Survey of major and minor sugar and starch components of white potato. Journal of Agricultural and Food Chemistry 2, 1284-1288.

Segura, M.I., Díaz, M.J. 2001. Procesos de Elaboración de Productos IV Gama. 4º Premio Directorio Poscosecha. 35 pp.

Singleton, V.L., Rossi, J.A. 1965. Colorimetry of total phenolics withphosphomolybdic–phosphotungstic acid reagents. American Journal of Enology and Viticulture 16, 144–158.

Smith, O. 1987. Transport and storage of potatoes. In: Talaburt, W.F., Smith, O. (Eds.), Potato Processing. Van Nostrand Reinhold, New York, NY, USA, pp. 203-285.

Son, S.M., Moon, K.D., Lee, C.Y. 2000. Rhubarb juice as a natural antibrowning agent. Journal of Food Science 65, 1288–1289.

Subramanian, N., Venkatesh, P., Ganguli, S., Sinkar, V.P. 1999. Role of polyphenol oxidase and peroxidase in the generation of black tea theaflavins. Journal of Agriculture and Food Chemestry 47, 2571–2578.

Suslow T., Cantwell, M. 1997. Artichoke (Globe): Recommendations for maintaining postharvest quality. Dept. of Vegetable Crops, University of California, Davis, CA 95616. Dirección URL: http://postharvest.ucdavis.edu/pfvegetable/artichoke/ [Consulta: 20 de Noviembre 2012].

Suslow, T., Cantwell, M. 2002. Potato, immature early crop. Recommendations for maintaining postharvest quality. Department of Vegetable Crops, University of California, Davis, CA 95616. Dirección URL: http://postharvest.ucdavis.edu/pfvegetable/PotatoesEarly/. [Consulta: 4 de Diciembre 2012].

Tharanathan, R.N. 2003. Biodegradable films and composite coatings: past, present and future. Trends in Food Science and Technology 14, 71–78.

Thomson, C.A., Sporns, P. 1995. Fluorescence polarization immunoassays for potato glycoalkaloids. Journal of Agricultural and Food Chemistry 43, 254–260.

Thybo, A.K., Christiansen, J., Kaack, K., Petersen, M.A. 2006. Effect of cultivars, wound healing and storage on sensory quality and chemical components in pre-peeled potatoes. LWT-Food Science and Technology 39, 166-176.

Toivonen, P.M.A. 2004. Postharvest storage procedures and oxidative stress. HortScience 39, 938–942.

Toivonen, P.M.A., Brummell, D.A. 2008. Biochemical bases of appearance and texture changes in fresh-cut fruit and vegetables. Review. Postharvest Biology and Technology 48, 1–14.

Toyotsu-cho, Suita-shi, 1997. Radiometric Instruments Operations 2-30: Precise Colour Communication. CD-ROM. Minolta, Co. Ltd. Osaka 564, Japan.

USDA. 2013. National Nutrient Data Base Nutrient Data for Potato, Flesh and Skin, Raw. Ultima actualización Septiembre 2012. Dirección URL: http://ndb.nal.usda.gov/ndb/foods/show/3065

Vámos-Vigázó, L. 1995. Prevention of enzymatic browning in fruits and vegetables. A review of principles and practice. In: Lee, C.Y., Whitacker J.R., (Eds.),

Enzymatic Browning and its Prevention. American Chemical Society, Washington, DC, USA, pp. 49–62.

Van Loo, J., Cummings, J., Delzenne, N., Englyst, H., Franck, A., Hopkins, M., Kok, N., Macfarlane, G., Newton, D., Quigley, M., Roberfroid, M., Van Vliet, T., Van den Heuvel, E. 1999. Functional food properties of non-digestible oligosaccharides: A consensus report from the ENDO project (DGXII AIRII-CT94-1095). British Journal of Nutrition 81, 121–132.

Vilas-Boas, E.V.B., Kader, A.A. 2006. Effect of atmospheric modification, 1-MCP and chemicals on quality of fresh-cut banana. Postharvest Biology and Technology 39, 155–162.

Walker, J.R.L. 1975. Enzymic browning in foods: a review. Enzyme Technology Digest 4, 89–100.

Wang, M., Simon, J.E., Aviles, I.F., He, K., Zheng, Q.V., Tadmor, Y. 2003. Analysis of antioxidative phenolic compounds in artichoke. Journal of Agricultural and Food Chemistry 51, 601–608.

Weller, A., Sims, C.A., Matthews, R.F., Bates, R.P. Brecht, J.K. 1997. Browning susceptibility and changes in composition during storage of carambola slices. Journal of Food Science 62, 256-260.

Whitaker, J.R. 1994. Principles of Enzymology for the Food Sciences. 2nd ed. Marcel Dekker, New York, NY, USA.

Wiley, R.C. (Eds.). 1994. Minimally Processed Refrigerated Fruits and Vegetables. Chapman & Hall, New York, NY, USA, 368 p.

Yahia, E. 1995. La tecnología de las atmósferas modificadas y controladas. Horticultura Internacional, 8, 20-25.

Yasui, H., Sakurai, H. 2003. Age-dependent generation of reactive oxygen species in the skin of live hairless rats exposed to UVA light. Experimental Dermatology 12, 655–661.

Zhu, X., Zhang, H., Lo, R. 2004. Phenolic compounds from the leaf extract of artichoke (*Cynara scolymus* L.) and their antimicrobial activities. Journal of Agricultural and Food Chemistry 52, 7272–7278.