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Estudio del efecto del procesado e ingredientes funcionales en la textura de purés de patata frescos y congelados

MEMORIA PARA OPTAR AL GRADO DE DOCTORA
PRESENTADA POR

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Estudio del efecto del procesado e ingredientes funcionales en la textura de purés de patata frescos y congelados

Tesis Doctoral presentada por

MARÍA JOSÉ JIMÉNEZ SÁNCHEZ

Realizada bajo la dirección de los doctores

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DOÑA MARÍA DOLORES ÁLVAREZ TORRES, DRA. INGENIERA AGRÓNOMA Y CIENTÍFICA TITULAR DEL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS (CSIC) Y DON WENCESLAO CANET PARREÑO, DR. INGENIERO AGRÓNOMO Y PROFESOR DE INVESTIGACIÓN DEL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS (CSIC),

CERTIFICAN:

Que la memoria titulada "**Estudio del efecto del procesado e ingredientes funcionales en la textura de purés de patata frescos y congelados"** presentada por la Licenciada en Biología **María José Jiménez Sánchez para optar al grado de Doctora**, ha sido desarrollada bajo su dirección con total dedicación y rigor científico en el Instituto de Ciencia y Tecnología de Alimentos y Nutrición del Consejo Superior de Investigaciones Científicas (ICTAN-CSIC) y, considerando que de acuerdo a la legislación vigente cumple con todas las exigencias académicas para su presentación, lectura y defensa como trabajo de Tesis Doctoral, autorizan su presentación para que sea juzgada por el tribunal correspondiente.

Y para que así conste a los efectos oportunos, firman el presente certificado en Madrid, a de 25 de febrero de 2015.

Dra. María Dolores Álvarez Torres | Prof. Dr. Wenceslao Canet Parreño

“Me enseñaron que el camino del progreso no es rápido ni fácil”

Marie Salomea Curie (1867-1934)

Premio Nobel de Física, 1903.

Premio Nobel de Química, 1911.

“Nunca consideres el estudio como una obligación, sino como una oportunidad para penetrar en el bello y maravilloso mundo del saber”

Albert Einstein (1879-1955)

Premio Nobel de Química, 1921.

“La ciencia siempre vale la pena porque sus descubrimientos, tarde o temprano, siempre se aplican”

Severo Ochoa (1905-1993)

Premio Nobel de Medicina, 1959.

A mis padres,

a mi hermano y a Raúl,

el hombre de mi vida.

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CAPÍTULO 1

INTRODUCCIÓN

En los últimos años el contexto económico, social y cultural ha generado que en los hogares de los países desarrollados cada vez se dedique menos tiempo a la preparación de platos elaborados de forma tradicional. La necesidad de comodidad y rápidez experimentada por los consumidores debido al ritmo de vida incesante en las grandes urbes ha fomentado la expasión en el mercado de platos precocinados y alimentos congelados. Simultáneamente, la dieta de la población de los países industrializados ha experimentado cambios sustanciales, aumentando la ingesta calórica total debido en parte al reducido consumo de hidratos de carbono complejos, fibra, vegetales y frutas. Los datos de los últimos años sobre obesidad, adulta e infantil, y enfermedades cardiovasculares han generado un aumento de la preocupación y concienciación social por la necesidad de introducir una alimentación y hábitos de consumo más saludables. Como consecuencia de este reciente y creciente interés por una alimentación más sana, la industria alimentaria está realizando una fuerte inversión en el desarrollo de los denominados alimentos funcionales, llamados así porque además de cubrir las necesidades metabólicas del individuo, afectan beneficiosamente a una o más funciones del organismo de modo que mejoran el estado de salud o bienestar, reduciendo el riesgo de enfermedades (Diplock y col., 1999). La necesidad de demostrar científicamente los efectos reductores o preventivos de enfermedad a consecuencia del consumo de alimentos funcionales está provocando que la Comunidad Científica Internacional realice un gran esfuerzo en el estudio de los mecanismos por los que los componentes de alimentos funcionales afectan a una determinada función en el organismo. Una línea fundamental de investigación para el diseño y desarrollo de alimentos funcionales consiste en la modificación de la formulación de un alimento tradicional eliminando o sustituyendo determininados ingredientes (grasa, azúcar, etc.) o adicionando compuestos de características saludables contrastadas (fibra soluble, ácidos graso, vitaminas, fitoesteroles, etc.) (Fogliano y Vitaglione, 2005).

Entre la variedad de ingredientes funcionales que existen en el mercado, y en base a las ventajas que ofrecen las fibras solubles (Schaafsma y col., 2015), los ácidos grasos monoinsaturados tipo oléico (Pampaloni y col., 2014; Fuccelli y col., 2014) y la proteína de soja (Tang y col., 2012), se consideró de especial interés estudiar el efecto de la adición individual de inulina de cadena larga, aceite de oliva virgen extra y aislado de proteína de soja en las características reológicas, de textura y calidad sensorial final de puré de patata natural, tanto recién elaborado como tras un proceso de congelación/descongelación. Del mismo modo, se estudia el efecto de incorporar mezclas de los mencionados ingredientes funcionales, de forma que el consumo del puré que los contenga contribuya a la ingesta recomendada de cada uno de ellos, investigando el efecto producido en la calidad del puré como consecuecia de la posible existencia de fenómenenos de sinergismo o antagonismo entre los constituyentes del producto.

Las modificaciones en la composición de los alimentos convencionales, así como el procesado, pueden provocar cambios en las propiedades organolépticas de dichos alimentos que a su vez pueden afectar a la calidad sensorial de los mismos. Una de las propiedades con mayor importancia en la calidad de los productos de patata recién elaborados y procesados es la textura, o llamada con más rigor “propiedades texturales”, ya que está directamente relacionada con su calidad sensorial. Por tanto, el estudio de cómo puede afectar a las propiedades texturales la reformulación de un producto es de vital importancia para la industria alimentaria, donde la innovación y el desarrollo de nuevos alimentos funcionales deben cubrir las preferencias y la aceptación de los consumidores finales.

Durante bastante tiempo, la disciplina de la tecnología de los alimentos ha desarrollado métodos instrumentales que permiten medir la textura (Pons y Fiszman, 1996). No obstante, un análisis más exhaustivo de la textura puede obtenerse mediante la correlación de las propiedades texturales obtenidas de forma instrumental con aquellas derivadas de una evaluación sensorial. Los perfiles sensoriales obtenidos de los productos mediante un análisis descriptivo son esenciales para definir y cuantificar las características sensoriales que diferencian dichos productos. Esto permite a las empresas alimentarias optimizar el producto acercándolo a la composición final deseada para su consumo. Tanto el perfil sensorial de textura como el análisis descriptivo cuantitativo (QDA®) son técnicas convencionales y muy utilizadas para describir y cuantificar las variaciones en las propiedades sensoriales de los alimentos. Ambas técnicas son realizadas por un panel de jueces entrenados o expertos utilizando términos específicos y complejos para definir los atributos sensoriales percibidos. Junto con la dificultad para interpretar el vocabulario utilizado así como el procedimiento para la evaluación de los atributos definidos, estos métodos ofrecen otra desventaja en relación al proceso largo y tedioso de entrenamiento de los jueces. La información obtenida mediante estas técnicas, aunque precisa y detallada, puede estar alejada de las diferencias percibidas por los consumidores en una situación real de consumo (Tarancón, 2013).

Actualmente se están aplicando nuevas técnicas sensoriales descriptivas que se pueden utilizar de forma alternativa y/o complementaria a las metodologías convencionales y que pueden resolver algunas de las limitaciones descritas. Una de éstas metodologías es el Flash Profile (Dairou y Sieffermann, 2002) que combina el Perfil de Libre Elección y el Método de Ordenamiento; sus características más prácticas son que cada miembro del panel genera su propio conjunto de atributos de forma individual, y que la evaluación se realiza mediante una comparación simultánea de todas las muestras permitiendo una mejor discriminación del producto. Otra de las técnicas que resultan atractivas es el Projective Mapping y su variante el Napping®, desarrolladas por Pagès (2005), en la que los jueces tienen que situar las muestras en un espacio bidimensional en función de sus similitudes o diferencias utilizando para dicho posicionamiento su propio criterio individual lo que hace del Projective Mapping un procedimiento flexible y espontáneo (Moussaoui y Varela, 2010). Este método puede combinarse con una breve descripción de las muestras por parte de los jueces con lo que se obtiene un perfil mucho más completo (Pagès, 2003; Perrin y col., 2008). Tanto para la realización del Flash Profile como del Projetive Mapping no es necesaria la participación de un panel de jueces entrenados o expertos, con lo que el tiempo empleado en su entrenamiento se ve claramente reducido, además como los miembros del panel utilizan su propio vocabulario la descripción del producto se acerca más a las expectativas y preferencias de los consumidores.

Todas las técnicas instrumentales junto con las nuevas metododologías sensoriales aplicadas en la presente Tesis Doctoral pueden ayudar a estudiar el efecto de la adición de ingredientes funcionales en la modificación de las propiedades texturales de los purés de patata frescos y congelados, definiendo mejor las características de estos productos. Aunque algunas de estas técnicas se han utilizado con éxito en diferentes alimentos, no se ha encontrado bibliografía referente a purés de patata frescos y procesados, por lo que su aplicación podría suponer una vía interesante de estudio.

CAPÍTULO 2

OBJETIVOS Y ESTRUCTURA DE LA TESIS DOCTORAL

2.1. OBJETIVOS DE LA TESIS DOCTORAL

El objetivo principal de la presente Tesis Doctoral fue estudiar el efecto del procesado y de la adición de distintos ingredientes funcionales en la textura de purés de patata frescos y congelados, mediante metodologías sensoriales e instrumentales que permiten caracterizar y optimizar la calidad tecnológica y sensorial de este tipo de productos.

Para alcanzar este objetivo se establecieron los siguientes objetivos parciales y específicos:

- Evaluar los efectos de añadir aceite de oliva virgen extra en las propiedades texturales, físicas, estructurales y sensoriales de purés de patata recién elaborados o frescos y posteriormente a su congelación.
- Estudiar los efectos que tiene la adición de diferentes mezclas de inulina y aceite de oliva virgen extra sobre las características texturales, físicas y sensoriales de purés de patata frescos y congelados.
- Identificar y reducir el número de atributos sensoriales que describen la textura percibida en los purés de patata recién elaborados y tras su congelación, formulados con diferentes mezclas de inulina y aceite de oliva virgen extra.
- Validar estadísticamente los efectos que tiene sobre la textura de purés de patata frescos y congelados, la adición de una mezcla de aislado de proteína de soja e inulina en diferentes proporciones, y analizar las diferencias entre los productos, comparando las actuaciones de un panel de jueces entrenados y otro compuesto por jueces no entrenados.

- Conocer el grado de correlación existente entre la textura percibida y las propiedades reológicas y estructurales de purés de patata frescos y congelados formulados con diferentes mezclas de aislado de proteína de soja e inulina.
- Caracterizar los purés de patata congelados y formulados con inulina, aceite de oliva virgen extra y aislado de proteína de soja, aplicando dos metodologías sensoriales innovadoras (Flash Profile y Projective Mapping) mediante la utilización de dos paneles de jueces con diferentes grados de entrenamiento.
- Comparar los perfiles sensoriales generados a través de estos dos métodos sensoriales innovadores con el perfil sensorial obtenido mediante un análisis descriptivo cuantitativo convencional, realizado por un panel de jueces entrenado.

2.2. ESTRUCTURA DE LA TESIS DOCTORAL

El trabajo de investigación realizado ha dado origen a cuatro publicaciones científicas cuyo contenido se muestra en el *Capítulo 4: "Trabajos experimentales"* de la presente Tesis Doctoral. Las referencias de estas publicaciones son:

- **Alvarez, M.D., Fernández, C., Jiménez, M.J. and Canet, W. (2011)**. Texture of extra virgin olive oil-enriched mashed potatoes: sensory, instrumental and structural relationships. Journal of Texture Studies, 42, 413-429.
- **Alvarez, M.D., Fernández, C., Olivares, M.D., Jiménez, M.J. and Canet, W. (2013)**. Sensory and texture properties of mashed potato incorporated with inulin and olive oil blends. International Journal of Food Properties, 16, 1-21.

- **Alvarez, M.D., Jiménez, M.J., Olivares, M.D., Barrios, L. and Canet, W. (2012)**. Texture perception determined by soy protein isolate and inulin addition in potato puree: links with mechanical and microstructural features. Journal of Texture Studies, 43, 361-374.
- **Jiménez, M.J., Canet, W. and Alvarez, M.D. (2013)**. Sensory description of potato puree enriched with individual functional ingredients and their blends. Journal of Texture Studies, 44, 301-316.

En la primera publicación se evaluaron los efectos de añadir aceite de oliva virgen extra en la textura instrumental y en los atributos sensoriales de purés de patata recién elaborados y congelados/descongelados, formulados sin y con crioprotectores (al objeto de minimizar el daño causado por la congelación y descongelación). Para ello, se estudiaron y analizaron los resultados de utilizar diferentes concentraciones de aceite de oliva virgen extra, de la incorporación de una mezcla de dos polisacáridos (kappa-carragenato y goma xantana) para la estabilización del puré de patata, y del procesado de la muestras en las propiedades texturales derivadas de ensayos de extrusión inversa y penetración cónica, en las propiedades físicas (color y sinéresis), en la microestructura de los purés y en los atributos sensoriales derivados de un análisis de perfil de textura (TPA).

Con la finalidad de obtener un producto rico en fibra soluble, en el segundo trabajo se enriquecieron los purés de patata elaborados con aceite de oliva virgen extra mediante la adición de inulina. Se estudiaron los efectos que la mezcla de ambos ingredientes funcionales tuvo en las propiedades de textura sensoriales e instrumentales, tanto en purés frescos como en purés congelados/descongelados, elaborados ambos con y sin crioprotectores. Además, aplicando el análisis de componentes principales, se identificaron y redujeron los atributos sensoriales que describen la textura, mediante combinaciones lineales de dichos atributos.

En el tercer trabajo experimental se estudió el efecto que la adición de mezclas de aislado de proteína de soja e inulina produce en la textura de purés de patata recién elaborados y congelados/descongelados mediante la evaluación de las propiedades reológicas, microestructurales y sensoriales. El estudio de las propiedades sensoriales se abordó utilizando un enfoque fundamentalmente estadístico, considerando a los jueces como efectos fijos o aleatorios, lo que permitió validar las evaluaciones de los paneles sensoriales utilizados (entrenado y no entrenado), valorar el nivel de acuerdo en las evaluaciones sensoriales realizadas por los miembros de cada panel, así como la correlación de los resultados de ambos paneles.

En la cuarta y última publicación, para la caracterización sensorial de este tipo de productos se profundizó en la aplicación de dos nuevas metodologías sensoriales descriptivas, Flash Profile y Projective Mapping, mediante la utilización de paneles con diferentes grados de entrenamiento. A través del uso de las citadas técnicas sensoriales, se evaluaron purés de patata elaborados con tres ingredientes funcionales (aceite de oliva virgen extra, inulina y aislado de proteína de soja) y los resultados se compararon con los obtenidos tras su evaluación mediante una metodología descriptiva cuantitativa convencional en la que participaron jueces entrenados. El trabajo de este último panel, se ve reflejado no sólo en el resto de capítulos de la presente Tesis Doctoral, sino también en numerosos estudios realizados, a lo largo de ocho años, por este grupo de investigación. Otro aspecto considerado en este capítulo fue la correlación de las características de textura instrumental con los atributos sensoriales generados por cada uno de los tres paneles de jueces.

Así mismo, el trabajo experimental desarrollado para llevar a cabo la presente Tesis Doctoral, ha permitido obtener paralelamente los siguientes trabajos científicos:

- **Canet, W., Fernández, C., Olivares, M.D., Jiménez, M.J. and Alvarez, M.D. (2010)**. Effect of inulin and extra virgin olive oil blends on sensory and instrumental texture measurements of mashed potatoes. 4th European Conference on Sensory and Consumer Research. A Sense of Quality. Vitoria (Spain).
- **Jiménez, M.J., Canet, W. and Alvarez, M.D. (2012)**. Chapter 1: Dynamic rheology and sensory properties determined by inulin/extra virgin olive oil blends in mashed potatoes: effects of hydrocolloids addition and freeze/thaw. In Book tittle: Olive Consumption and Health. A. Savalas and Soussana M. Nicolau (Eds), pp: 1-42. Nova Science Publishers, Inc, NY, USA. ISBN: 978-1-62100-774-6.
- **Jiménez, M.J., Canet, W. and Alvarez, M.D. (2013)**. Chapter 1: Descriptive Sensory Analysis of Food: Conventional versus Innovative Methodologies. In Book tittle: New Developments in Sensory Processing Research. M. Voisin and R. Brunel (Eds), pp: 1-51. Nova Science Publishers, Inc, NY, USA. ISBN: 978-1-62808-399-6.
- **Alvarez, M.D., Canet, W. and Jiménez, M.J. (2014)**. Chapter 1: Rheology, texture and functionality of soy protein isolate-based potato puree: instrumental, sensory and structural relationships. In Book tittle: Soy Protein: Production Methods, Functional Properties and Food Sources. Jon M. Casamides and H. Gonzalez (Eds), pp: 1-46. Nova Science Publishers, Inc, NY, USA. ISBN: 978-1-62948-579-9.

CAPÍTULO 3

REVISIÓN BIBLIOGRÁFICA

3.1 EL PURÉ DE PATATA: INGREDIENTES Y SITUACIÓN ACTUAL.

3.1.1 MATERIA PRIMA

La selección de la patata como materia prima para la elaboración de los purés estudiados en la presente Tesis Doctoral, es debida a su elevada importancia económica por ser un producto que ocupa una posición única en la dieta humana ya que posee un alto valor nutricional y es una fuente considerable de energía.

La patata (*Solanum tuberosum L.*) es originaria de la Cordillera de los Andes, existiendo actualmente más de 4.500 variedades catalogadas y cultivadas en más de 100 países (Pieterse y Judd, 2014). En el siglo XVI fue traída a Europa por los españoles, adaptándose con rapidez a las condiciones del norte por lo que pronto se convirtió en alimento básico en una época de acelerado crecimiento demográfico.

Según la División Estadística de la FAO (FAOSTAT), los principales países productores de patata son China, India, Rusia, Ucrania y Estados Unidos. Con una producción mundial de más de 365 millones de toneladas en el año 2012, la patata representa el cuarto alimento básico del mundo, después del maíz, el trigo y el arroz. La producción en España se ha mantenido relativamente constante en los últimos dos años, situándose alrededor de los 2 millones de toneladas (FAO, 2013).

Debido a sus propiedades nutritivas y al coste de su producción, la patata está siendo de vital importancia en países en vías de desarrollo con escasos recursos económicos donde la población padece carencias alimenticias extremas. Un claro ejemplo puede encontrarse en las zonas urbanas del África subsahariana, donde las patatas han adquirido gran popularidad y, se han convertido en un alimento básico fundamental y en un importante cultivo comercial. Como señaló Eric Keuneman, Jefe del Servicio de Cultivos y Pastos de la FAO: “Para las personas de bajos ingresos de las zonas urbanas y rurales, la patata realmente es un tesoro enterrado”.

Según la variedad, la patata contiene, aproximadamente, un 78% de agua y un 22% de materia seca. De esa materia seca, entre el 60% y el 80% corresponde a almidón, lo que hace de la patata un alimento saludable. Además, la patata contiene proteínas, poca grasa y abundantes micronutrientes, especialmente vitamina C y una cantidad moderada de hierro. Así mismo, este tubérculo tiene vitaminas B1, B3 y B6, ácido pantoténico y riboflavina, y otros minerales como potasio, fósforo y magnesio, así como fibra y compuestos antioxidantes, los cuales pueden contribuir a prevenir enfermedades relacionadas con el envejecimiento.

El componente sólido mayoritario de la patata, **el almidón**, es un polisacárido de glucosa anhidra, constituido por dos componentes: amilosa y amilopectina. La amilosa es un polímero lineal y soluble en agua caliente (70-80 ºC), mientras que la amilopectina es ramificada e insoluble. Ambas están formadas por unidades de glucosa; en el caso de la amilosa unidas entre ellas por enlaces α-(1→4), lo que da lugar a una cadena lineal, mientras que en la amilopectina aparecen ramificaciones debidas a enlaces α-(1→6), cada 20 o 30 glucosas (Aberle y col., 1994).

Las propiedades funcionales aportadas por el almidón (textura, viscosidad y retención de humedad, entre otras) se desarrollan cuando los gránulos gelatinizan. El **proceso de gelatinización** ocurre al calentar los gránulos de almidón en presencia de agua. En la gelatinización se producen cambios irreversibles como fusión cristalina, pérdida de birrefringencia y solubilización (Mitolo, 2006).

La gelatinización del almidón tiene lugar en exceso de agua y condiciones de humedad limitadas en un intervalo de temperatura, que se conoce como temperatura de gelatinización y depende de la variedad (Alvarez, 1996). Durante la gelatinización del almidón, parte de la amilosa difunde del gránulo (Smith, 1980) y las regiones de amilopectina cristalina absorben agua, dando lugar a un hinchamiento de los gránulos de almidón. Estos cambios van acompañados de un aumento de viscosidad del producto debido a que los gránulos de almidón se adhieren unos a otros (Whistler y Daniel, 1993).

En el proceso de enfriamiento de la suspensión gelatinizada, la pérdida de la estructura ovalada y cristalina del gránulo de almidón, ocurrida durante la gelatinización, es parcialmente recuperada debido a que las cadenas lineales de amilosa se orientan paralelamente y se unen de nuevo mediante puentes de hidrógeno formándose una red reticular tridimensional. Cuando este reordenamiento ocurre, el agua retenida es expulsada fuera de la red, es decir, se separan la fase sólida (cristales de amilosa y de amilopectina) y la fase acuosa (agua líquida). Esta intensa e irreversible transición desde el estado soluble o disperso a otro insoluble, no hinchado y microcristalino, se conoce como **retrogradación del almidón** (Whistler y Daniel, 1993). El proceso de exclusión de agua que acompaña a la retrogradación se denomina **sinéresis**. La retrogradación produce un aumento de las propiedades texturales dureza y cohesividad y una disminución de la adhesividad y de la fracturabilidad, especialmente manifiestos a 4 ºC, que están relacionados con la disminución de la amilosa soluble y con el desarrollo de una red polimérica en el almidón gelatinizado (Alvarez, 1996).

La gelatinización y retrogradación son las dos propiedades funcionales más importantes del almidón. Un calentamiento paulatino de tubérculos en medio acuoso, es decir, la cocción de patatas, ocasiona la separación de las células y la gelatinización del almidón (Reeve, 1977), y a su vez, el enfriamiento promueve su retrogradación (Jankowski, 1992).

La tendencia del almidón a retrogradarse se ve favorecida por las bajas temperaturas (especialmente en torno a 0 ºC), pH neutro y concentraciones altas de almidón. El grado de retrogradación dependerá también del peso molecular y del tipo de almidón (Eliasson y Kim, 1992; Achayuthakan y Suphantharika, 2008).

Una opción para mejorar el comportamiento de los almidones nativos consiste en combinarlos con otros hidrocoloides, capaces de ligar e inmovilizar agua.

3.1.2 CRIOPROTECTORES

Los procesos de congelación y descongelación inducen fenómenos de sinéresis e inestabilidad, produciéndose agregaciones y sedimentaciones que causan el deterioro de la textura de los purés vegetales (Downey, 2002). Una estrategia para minimizar el daño causado por dichos procesos consiste en la adición de crioprotectores que interaccionan con el agua (Sych y col., 1990), disminuyendo la velocidad de crecimiento de los cristales de hielo, alterando su forma (Bolliger y col., 2000) y ofreciendo protección frente a los efectos perjudiciales de la descongelación en particular.

Los crioprotectores utilizados en la industria alimentaria son adicionados a distintos productos con fines tales como controlar la estructura, textura y estabilidad frente al procesado. Los dos crioprotectores más utilizados son los polisacáridos y las proteínas.

Los polisacáridos poseen efecto crioprotector para hacer frente a necesidades específicas como es la mejora de la textura. Así mismo, se caracterizan particularmente por su capacidad de retención de agua (Dickinson, 1998).

El interés tecnológico de las mezclas de polisacáridos, en particular entre el almidón y otros polisacáridos, es motivado por la aptitud que las mezclas de estas macromoléculas tienen para influir en la capacidad de gelificación, emulsificación, modificación de la viscosidad, estabilización de suspensiones y capacidad de retención de agua además de proporcionar atractivas propiedades funcionales (Medina-Torres y col., 2003). Los hidrocoloides, por tanto, son utilizados en productos elaborados a base de almidón para controlar la gelatinización y las propiedades reológicas de los almidones. Procesos como la cocción de pan y pasteles, extrusión de productos a base de cereales, espesamiento y gelificación de salsas, cremas, purés vegetales y rellenos de pasteles, son todos dependientes de la gelatinización del almidón durante su utilización industrial.

Downey (2002) estudió el efecto de la adición de varios hidrocoloides (goma xantana, goma guar, pectina y carragenato) y de proteínas lácteas (caseinato sódico y concentrado proteico del lactosuero) en la sinéresis y en la máxima resistencia a la penetración en purés vegetales congelados y descongelados, poniendo de manifiesto que dependiendo del vegetal, se puede mantener su calidad o mejorarla después de la descongelación a través de la selección apropiada de un crioprotector. El tipo y la concentración del hidrocoloide influyen de manera considerable en la textura y las propiedades sensoriales de este grupo de productos.

Se han llevado a cabo diferentes estudios dirigidos a cuantificar las características reológicas de los hidrocoloides individualmente o en formulaciones de alimentos (Krumel y Sarkar, 1975; Sanderson, 1981; Dickie y Kokini, 1983; Stanley, 1990; White y col., 1993; Abdelrahim y col., 1995; Da Silva y Rao, 1995; Ma y Barbosa-Canovas, 1996; Da Silva y col., 1997; Fernández, 2008; Albert, 2011; Morell y col., 2014; Tárrega y col., 2014).

En la presente Tesis Doctoral se eligieron dos polisacáridos como crioprotectores para su adición a los purés de patata estudiados. Esta decisión tiene su origen en los estudios realizados previamente por este grupo de investigación con diferentes crioprotectores (pectina de bajo metoxilo, goma xantana, kappa-carragenato y caseinato sódico) y sus mezclas, y que tuvieron como fruto diversas publicaciones científicas (Alvarez y col., 2011; Canet, 2011) y una patente de invención (Canet y col., 2010).

Los resultados más notables de dichos estudios permitieron concluir que, la mezcla óptima de crioprotectores es la formada por la goma xantana y el kappa-carragenato, ambos adicionados en concentraciones individuales de 1,5 g kg^{-1}.

La incorporación de los dos polisacáridos logra inhibir el deterioro de la textura consecuencia de fenómenos de sinéresis e inestabilidad inducidos por el proceso de congelación. Además, hace que los purés de patata estudiados en la presente Tesis Doctoral presenten unas características reológicas, texturales, de color y organolépticas similares, e incluso superiores, tanto a las de los productos comercializados actualmente, como a las que posee un puré de patata fresco elaborado de forma convencional.

Como ya se ha mencionado, uno de los hidrocoloides utilizados fue el **kappa-carragenato (k-C)**. Éste es un polisacárido lineal aniónico sulfatado, concretamente poligalactano de alto peso molecular, formado por la repetición alternada de unidades de D-galactosa y de 3-6 anhidro-D-galactosa que se unen mediante enlaces glicosídicos alternos α-(1→3) y β-(1→4), y pueden estar presentes grupos éster sulfato en algunas o en todas las unidades de galactosa (Stanley, 1990). En el k-C, la unidad ligada en posición 4 se encuentra como 3-6 anhidro, lo que posibilita a la molécula adoptar la estructura ordenada de doble hélice necesaria para la gelificación (Rees y col., 1982).

Existen diversos estudios de su aplicación en alimentos relativos a su combinación con almidones (Lai y col., 1999; Autio y col., 2002; Tecante y Doublier, 2002; Verbeken y col., 2004; Arocas, 2010). El k-C ha sido principalmente utilizado como agente gelificante en productos lácteos (Arltoft y col., 2008).

El otro hidrocoloide utilizado en la presente Tesis Doctoral fue la **goma xantana (XG)**: heteropolisacárido extracelular, de alto peso molecular, producido por diversas especies de bacterias del género *Xanthomonas campestris,* siendo la B-1459 la bacteria utilizada comercialmente para su síntesis (Katzbauer, 1998; Song y col., 2006). La XG está formada por unidades de β-D-glucosa unidas por enlaces β-(1→4), una rama trisacárida constituida por una unidad de ácido glucurónico entre dos unidades de manosa se une a cada unidad de glucosa en la posición 3 (Jansson y col., 1975).

La XG presenta una elevada capacidad de retención de agua, por lo que ofrece una excelente estabilidad frente a los procesos de congelación y descongelación (García-Ochoa y col., 2000). Por ello, se utiliza en productos de panadería, proporcionando estabilidad durante la cocción y el enfriamiento de la harina de trigo, ofreciendo la posibilidad de mejorar la calidad del pan, tanto durante la conservación en el estado congelado como en su descongelación en microondas. En este último proceso es deseable un aumento de la capacidad de retención de agua, con el fin de obstaculizar la pérdida rápida de agua que se produce, obteniéndose así un producto menos duro (Mandala, 2005). La XG se utiliza también para mejorar la textura de salsas, mezclas de formulaciones secas, confitería y productos lácteos como agente aglutinante, espesante, estabilizador y agente que proporciona cuerpo a los productos, entre otros (Mandala y col., 2004).

La adición de gomas en general, y de XG en particular, estabiliza la textura de las dispersiones de alimentos (Hoefler, 2004), por lo que puede utilizarse para estabilizar y mejorar las propiedades reológicas de puré de patata, tanto fresco como después de ser sometido a un proceso de congelación. Varios autores han estudiado el efecto de diferentes gomas en las propiedades reológicas de dispersiones de alimentos, tales como rellenos de frutas (Wei y col., 2001), ketchup (Sahin y Ozdemir, 2004), salsas (Mandala y col., 2004), pastas (Choi y Yoo, 2006), nuggets (Albert, 2009) y salsas blancas (Arocas, 2010).

3.1.3 SITUACIÓN ACTUAL

El desarrollo económico y el crecimiento progresivo de los países industrializados inducen nuevas realidades sociales, entre ellas la reducción drástica del tiempo dedicado a la preparación doméstica de los alimentos. La necesidad de productos elaborados y la exigencia cada vez mayor del consumidor, ha sido respondida por la industria alimentaria con una enorme expansión de los alimentos congelados. El mercado de comidas preparadas congeladas representa en España uno de los mayores subsectores en términos de volumen y valor económico. Junto con la ventaja de una mayor vida útil, las comidas preparadas basadas en vegetales como es el caso del puré de patata, y dado el tedioso proceso de elaboración que requiere, sería interesante disponer de productos de este tipo congelados, tanto para la restauración colectiva como para el consumo individual (Fernández, 2008).

Además, nuestra conciencia cada vez mayor de la relación existente entre el alimento y la salud ha incrementado la demanda hacia alimentos con alto contenido en fibra y baja cantidad de grasa (Nishinari, 2009).

En nuestro mercado, es relativamente reciente la aparición de cremas vegetales que tomando como base la patata, han dado lugar a una variedad de productos refrigerados cuyo consumo a diferentes temperaturas permiten ser una fuente excelente de fibra, minerales y vitaminas indispensables en una dieta sana y equilibrada (Fernández, 2008). La combinación de sabor, textura y apariencia influye en la preferencia y aceptación que el consumidor tiene sobre estos productos. El puré de patata es un producto muy aceptado bien como acompañamiento de una comida preparada o como producto individual. Además el puré de patata, utilizado también como ingrediente fundamental para alimentación infantil en forma de potitos, presenta ventajas frente a otros alimentos infantiles basados en cereales, especialmente trigo y cereales relacionados, debido a su efecto hipoalergénico.

En el caso de la patata, y especialmente en los países desarrollados, su consumo está pasando del producto fresco a los productos procesados que, tomando como base la patata, permiten obtener alimentos con un alto valor añadido. En respuesta a la creciente demanda de los consumidores hacia alimentos de alta calidad, fáciles de preparar, se han desarrollado nuevas e innovadoras formas de utilización de la patata, siendo sus productos derivados congelados los más importantes. Asimismo, existen en el mercado una creciente y amplia variedad de comidas preparadas congeladas, que ofrecen además una manufacturación y flexibilidad sustancialmente más prolongada que la comida preparada refrigerada, la cual presenta una vida útil relativamente corta.

Multinacionales importantes como Heinz, Unilever o Conagrafoods, incluyen en su actividad un sector dedicado a la comercialización de productos congelados. Marcas como Boston Market, CountryCrock, Lamb Weston o Lutosa entre otras, cuentan entre sus productos estrella con el puré de patata congelado que además de ser fabricado como producto individual, se incluye en una gran variedad de platos congelados como componente principal o como guarnición. El puré de patata congelado es utilizado además de para la elaboración de patatas fritas estilo francés (tipo paja) y patatas fritas tipo chips (Lamberti y col., 2004), también como ingrediente base o intermedio en gran número de especialidades, formas y sabores como croquetas, bocaditos, gratinados, etc., siendo estas especialidades dirigidas a todo tipo de cocina y población (hindú, americana, asiática, mediterránea, etc.), y consumidas casi diariamente.

Actualmente, los únicos tipos de puré de patata que pueden ser adquiridos comercialmente en el mercado español son el puré de patata que se elabora a partir de copos o escamas desecados que es ampliamente aceptado, y un puré de patata a base de copos de patata deshidratados ya reconstituido con escaso éxito comercial. El puré de patata, principalmente desecado, se produce y consume a gran escala en un amplio número de países europeos (Reino Unido, Francia, Bélgica, Bulgaria…), Estados Unidos y Canadá (Redmond y col., 2002). Por lo tanto, se considera de alto interés y previsible éxito comercial la existencia de un puré de patata congelado cuya presentación final sea en raciones unipersonales o familiares y que, con una descongelación y calentamiento final rápido en microondas, permita tanto al consumidor como a la restauración colectiva disponer de un producto de alta calidad y estabilidad, para ser servido como un primer plato o como acompañamiento a los platos principales de cualquier comida, evitando el prolongado y tedioso procedimiento de preparación convencional (Canet, 2001).

Por otro lado, los purés de patata elaborados y estudiados en la presente Tesis Doctoral poseen también interesantes propiedades nutricionales y saludables, ya que han sido suplementados con tres ingredientes funcionales (aceite de oliva virgen extra, inulina y aislado de proteína de soja) cuyo beneficio para la salud humana ha sido demostrado (Tang y col., 2012; Fuccelli y col., 2014; Pampaloni y col., 2014; Schaafsma y col., 2015).

3.2 INGREDIENTES FUNCIONALES

El puré de patata en sí mismo es un alimento compuesto básicamente por almidón, que puede ser considerado como un sistema semisólido, es decir, es un material viscoelástico (Foegeding y col., 2011). Además del almidón nativo de la patata, los purés estudiados en la presente Tesis Doctoral constituyen un sistema combinado con proteína de leche desnaturalizada, agua y sal, junto con crioprotectores añadidos (kappa-carragenato y goma xantana) cuando los productos van a ser congelados (Alvarez y col., 2012).

Las variaciones en la composición de los purés de patata iniciales mediante la adición de nuevos ingredientes podrían producir notables diferencias en el producto final (Bayarri y col., 2011). Dicha adición de ciertos ingredientes funcionales y nutricionales (inulina, aceite de oliva virgen extra y aislado de proteína de soja) influirá en las características estructurales, fisicoquímicas, texturales y en la calidad sensorial del producto final. Además, mediante la suplementación de los purés con los mencionados ingredientes es posible obtener unos productos con mayor valor nutricional y mucho más saludables.

3.2.1 INULINA

La inulina (INL) es un componente natural de varias frutas y verduras aunque de forma industrial se produce principalmente a partir de la raíz de la achicoria en copos mediante una extracción a elevada temperatura seguida de un proceso de intercambio de iones (Dysseleer y Hoffem, 1995).

Químicamente, la inulina natural es una mezcla de cadenas de oligómeros y/o polímeros con un número variable de moléculas de fructosa que están unidas mediante enlaces glicosídicos beta (1→2), responsables de sus características nutricionales (Zimmeri, 2003). La última molécula de fructosa se une a su vez a una molécula de glucosa mediante un enlace glicosídico alfa (1→2) como en la sacarosa (Roberfroid, 1999).

El grado de polimerización de las cadenas oscila entre 2 y 60 unidades, así la inulina natural se caracteriza por un grado de polimerización medio de 12 unidades. Pueden obtenerse dos tipos de inulina, una de cadena corta, cuyo grado de polimerización oscila entre 2 y 7 unidades, mediante hidrólisis parcial enzimática de la INL nativa, y una inulina de cadena larga (grado de polimerización entre 22 y 25 unidades) mediante procesos físicos (Franck, 2002).

Desde un punto de vista fisiológico, la inulina es un carbohidrato no digerible con especial interés para la industria alimentaria, es precisamente la configuración beta que existe en sus monómeros de fructosa lo que garantiza a la inulina su carácter como fibra dietética (Flamm y col., 2001) ya que esta configuración la hace resistente a la hidrólisis en el intestino delgado debido a que las enzimas que actúan a este nivel del tracto digestivo son específicas para las uniones α-glicosídicas.

Por tanto, la inulina tiene beneficios saludables para el ser humano inherentes a su condición de fibra dietética, como son la regulación del tránsito intestinal, la reducción de los niveles de lípidos y colesterol en sangre y el incremento de la absorción de calcio (Roberfroid, 1993; Flam, 2001).

Otros beneficios reportados sobre la salud que aporta la inulina son aquellos derivados de su función prebiótica, relacionados principalmente con la estimulación del crecimiento de la bacterias beneficiosas (por ejemplo: bifidobacterias) (Roberfroid y col., 1999; Roberfroid y Slavin, 2000) y la disminución de crecimiento de fusobacterias y clostridium (Kaur y Gupta 2002).

La inulina ha sido añadida a diferentes alimentos en cantidades que varían desde los 3 g a los 6 g por ración, para incrementar la ingestión de fibra soluble, o para asegurar la producción de bífidus añadiendo entre 3 g y 8 g por ración (Coussement, 1999).

Además de los ya citados beneficios en la salud humana, la INL ofrece otras propiedades tecnológicas interesantes tales como actuar como un edulcorante bajo en calorías, sustitutivo de grasa o agente de textura (Tungland y Meyer, 2002).

La inulina mezclada con disoluciones acuosas desarrolla una estructura de gel formada por una red de partículas cristalinas (Hébette y col., 1998; Chiavaro y col., 2007), cuyas propiedades se asemejan más a las de una red de cristales de grasa en el aceite (Bot y col., 2004). Esta estructura es blanca y cremosa, pudiéndose incorporar a alimentos para sustituir la grasa (Franck, 1993) ya que proporciona una textura untuosa y una sensación en boca cremosa (Frippiat y Smits, 1996).

La inulina tiene un sabor neutro, es incolora y tiene una mínima influencia sobre las características sensoriales de los alimentos por lo que puede ser considerada como forma invisible para poder añadir fibra a los alimentos. Son numerosos los estudios realizados sobre el efecto que tiene la adición de este ingrediente funcional sobre las características reológicas y sensoriales de una amplia variedad de productos como en helados (Schaller-Povolny y Smith, 2001; El-Nagar y col., 2002), yogures (Dello Staffolo y col., 2004; Guven y col., 2005; Kip y col., 2006; Brennan y col., 2008), queso fresco (Koca y Metin, 2004; Henelly y col., 2006), postres lácteos (Tárrega y Costell, 2006; Cardarelliy col., 2008), yogures bajos en grasa (Kip y col., 2006; Srisuvor y col., 2013) y bebidas lácteas (Villegas y Costell, 2007). Ha sido también utilizada en pasta (Brennany col., 2004), pasteles (Moscattoy col., 2006) y chocolates (Bolenz y col., 2006). Más recientemente, se han investigado los efectos que ejerce la inulina sobre parámetros de color y textura en carnes cocidas (Alvarez y Barbut, 2013) e incluso se han estudiado las propiedades acústicas y de fractura en galletas enriquecidas con este fructano (Laguna y col., 2013).

3.2.2 ACEITE DE OLIVA VIRGEN EXTRA

El aceite de oliva es un alimento muy presente en países de la región del Mediterráneo como España, Italia y Grecia, donde es considerado el alimento más representativo de la denominada “dieta mediterránea” y en la que proporciona el 85% del contenido de grasa (Muniz, 2007). En estas regiones, las características nutricionales del aceite son muy apreciadas y conocidas desde hace mucho tiempo por lo que es utilizado diariamente para una gran variedad de fines culinarios incluso en frituras debido a su remarcable resistencia a la oxidación térmica (Paraskevopoulou y col., 2005).

Gracias al interés creciente que está surgiendo sobre la dieta mediterránea y a la creencia de que el aceite previene ciertas enfermedades (Boskou y Visioli, 2003), su consumo ha aumentado considerablemente en las regiones fuera del área del Mediterráneo. Su interés, se consolidó con la inclusión de una declaración por parte de la Administración de Alimentos y Medicamentos (FDA) del Departamento de Salud y Servicios Humanos de los Estados Unidos (US Federal Drug Administration) en las etiquetas del aceite de oliva comercializado, donde se declara que el consumo de dos cucharadas (23 g) de aceite al día reduce el riesgo de sufrir enfermedades coronarias.

El aceite de oliva virgen extra (EVOO) es definido por el Consejo Internacional Oleícola (IOC) como aquel aceite obtenido únicamente del fruto del olivo (*Olea europaea L.*), la aceituna, que ha sido extraído sólo mediante procesos mecánicos o físicos sin la utilización de disolventes o procedimientos de reesterificación y, sin que haya sido mezclado con aceites de otra naturaleza. La acidez libre del EVOO expresada en ácido oleico debe ser como máximo de 0,8 g por 100 g. La ausencia del proceso de refinamiento ayuda a preservar el delicado aroma y las propiedades nutricionales y sensoriales que lo distinguen de otros aceites comestibles (Boskou y col., 2006).

Desde el punto de vista bromatológico, la composición del aceite de oliva puede dividirse en dos fracciones: una fracción mayoritaria, denominada saponificable que representa el 98-99% del peso total del aceite, y otra fracción minoritaria o insaponificable que alcanza sobre el 2% del peso del aceite de oliva. Entre los constituyentes de la fracción saponificable están los triglicéridos, componente principal del aceite de oliva, diglicéridos, monoglicéridos y ácidos grasos libres (Andrews y col., 2003). La fracción insaponificable incluye una gran variedad de compuestos químicos tales como fosfolípidos, ceras, esteroles libres, tocoferoles, clorofilas y carotenoides; sin embargo, lo que diferencia al EVOO de otros aceites comestibles son, en términos de composición, los compuestos minoritarios fenólicos y volátiles (Carrasco-Pancorbo y col., 2005; Bendini y col., 2007).

Los compuestos fenólicos poseen propiedades antioxidantes muy importantes jugando un papel principal en la aterogénesis y cáncer (Muniz, 2007), también contribuyen a las propiedades organolépticas del aceite de oliva virgen extra relacionándose principalmente con la astringencia y el sabor amargo (Servili y

Montedoro, 2002; Siliani y col., 2006; Beltrán y col., 2007). Estos atributos pueden permanecer en boca mucho tiempo después de la deglución pudiendo afectar a su aceptación por parte de los consumidores (Caporale y col., 2006). Por otro lado, los compuestos volátiles han sido relacionados con el aroma del aceite de oliva virgen extra (Cerretani y col., 2008).

Las propiedades organolépticas, nutricionales, culinarias y saludables han motivado la compra y consumición del aceite de oliva virgen extra, cumpliendo las expectativas tanto de los consumidores más expertos como de aquellos que se inician en el consumo un alimento más saludable, nutritivo y natural (Delgado y col., 2011). La tendencia en los últimos años ha sido elaborar productos con menor contenido en grasas, sin embargo, los consumidores son reacios a aceptar productos alimenticios con propiedades texturales y de sabor diferentes a aquellos productos tradicionales (Nagar y col., 2002). Por tanto, las demandas de los consumidores y de la industria alimenticia han generado un interés creciente por alimentos con reducido contenido en colesterol pero sin defectos sensoriales. En ocasiones, el EVOO ha sido utilizado para sustituir otras grasas vegetales como la margarina en la elaboración de pasteles (Matsakidou y col., 2010) estudiando su efecto sobre la dureza y la cohesividad. También se ha utilizado para sustituir parcial o totalmente la grasa animal en productos tales como "salami", estudiándose el efecto de dicha sustitución sobre la calidad química, física y sensorial (Severini y col., 2003), y aunque la textura de este alimento sufrió modificaciones, el producto resultante fue más saludable. Asimismo, se reportó que el uso de aceite de oliva en productos cárnicos para reemplazar la grasa animal puede ser beneficioso para la salud. Por otro lado, el aceite de oliva virgen extra ha sido añadido a productos vegetales, como purés de tomate y judías (Dinnella y col., 2012). Además, se han realizado estudios sobre la aceptabilidad del maíz sometido a un proceso de fritura con EVOO (Ryan y col., 2008).

3.2.3 AISLADO DE PROTEÍNA DE SOJA

Las proteínas son los ingredientes funcionales tecnológicos más importantes ya que poseen un amplio rango de propiedades funcionales dinámicas (sensoriales, kinestésicas, hidratantes, superficiales, reológicas y texturales) que pueden mostrar una versatilidad durante el procesado de los alimentos y mejorar los atributos de calidad de los mismos (Torrezan y col., 2007).

La proteína de soja es una fuente importante de proteínas vegetales que posee bajo contenido en grasa y un alto valor nutricional, además, debido a su bajo coste económico, es la proteína vegetal predominantemente disponible en los mercados de todo el mundo (Molina y col., 2002).

Durante siglos los productos que contienen soja han sido la fuente principal de proteínas vegetales en la dieta de los países orientales. Recientemente, el consumo de alimentos de soja ha aumentado de forma considerable como consecuencia de la atribución de beneficios nutricionales y sobre la salud humana, originados por una presencia equilibrada de todos los aminoácidos esenciales y un alto contenido en lisina. Friedman y Brandon (2001), publicaron que la consumición de soja previene enfermedades tales como el cáncer y la osteoporosis (Herrero y col., 2008). Asimismo, la Administración de Alimentos y Medicamentos del Departamento de Salud y Servicios Humanos de los Estados Unidos (US Federal Drug Administration (FDA)) aprobó una declaración de propiedades saludables de la proteína de soja referentes a la reducción sobre el riesgo de padecer enfermedades coronarias (Stewart, 2005).

Desde el punto de vista de desarrollo de productos, la proteína de soja ha sido utilizada en un amplio rango de alimentos debido a sus propiedades funcionales que mejoran la calidad de los productos alimenticios y, que hacen que la proteína de soja sea la proteína vegetal más utilizada en la industria alimenticia. Las propiedades funcionales más relevantes son la gelatinización, emulsión, solubilidad, espesante y capacidad de retener agua (Tseng y col., 2008; Liu y Kuo, 2010).

El aislado de proteína de soja (SPI) es la forma más refinada de la proteína de soja con un contenido mínimo en soja del 90%. El SPI está compuesto por dos fracciones proteicas globulares: 7S (β-conglicina) y 11S (glicina). El comportamiento funcional del SPI depende, fundamentalmente, del grado de desnaturalización, disociación y agregación de las dos subunidades así como del ratio (p/p) de esas dos fracciones proteicas (Tseng y col., 2009).

Los diferentes tratamientos aplicados durante la extracción y/o procesado del SPI causan cambios físicos y químicos en la proteína (Puppo y col., 2000). Esas modificaciones son las que hacen que el aislado de proteína de soja se haya convertido en un ingrediente alimenticio muy versátil que puede mejorar las características organolépticas y el valor nutricional de los productos alimenticios a los que se añaden (Tseng y col., 2009). Sistemas alimenticos tales como tofu, pasta, productos horneados, alimentos infantiles, bebidas y productos cárnicos, son algunos de los productos a los que se ha añadido SPI (Riaz, 2006; Hagenimana y col., 2007).

Así mismo, la adición de aislado de proteína de soja ha sido investigada en yogurts (Drake y col., 2002), helados (Friedeck y col., 2003), leche de soja (Chambers IV y col., 2006), carne (Youssef y Barbut, 2011) y geles de uva para confitería (Siegwein y col., 2011).

3.3 IMPORTANCIA DE LA TEXTURA Y LA REOLOGÍA EN EL PURÉ DE PATATA.

La mayoría de alimentos entre los que se encuentra el puré de patata no pueden clasificarse dentro del comportamiento típico de un líquido (viscosidad) ni de un sólido (elasticidad), ya que presentan un comportamiento viscoelástico, es decir, que presentan componentes de ambos comportamientos. El estudio de las propiedades viscoelásticas de los alimentos en términos de propiedades físicas bien definidas puede ser útil para caracterizar su textura y relacionarla con la estructura interna.

La textura de los alimentos es uno de los atributos primarios directamente relacionado con su calidad sensorial y además es determinante de la aceptabilidad de los alimentos por parte del consumidor (Fernández, 2008; Arocas, 2011).

La textura se define como “conjunto de propiedades reológicas y de estructura (geométricas y de superficie) de un producto, perceptibles por los mecanoreceptores, los receptores táctiles y en ciertos casos, por los visuales y auditivos” (UNE 2010, ISO 5492). Szczesniak (2002) define la textura como “una manifestación sensorial y funcional de las propiedades estructurales, mecánicas y de superficie de los alimentos detectada mediante los sentidos de la vista, oído, tacto y kinestésicos”.

Debido al carácter multidimensional y complejo de la textura, ha sido adoptado el término “propiedades texturales” que implica un espectro bastante más amplio de parámetros. Las propiedades texturales de un alimento están determinadas por las características físicas de los elementos estructurales del material y se relacionan con la respuesta a la deformación, modo de desintegración y flujo por la aplicación de una fuerza (Arocas, 2011). El acto habitual de comer puede considerarse como un acto de rotura, deformación y desintegración del alimento en la boca, por lo que el estudio de las propiedades reológicas de los alimentos cuando son sometidos a determinadas fuerzas se puede llegar a relacionar con la textura percibida, considerada como un factor principal de la calidad (Bourne, 1982; Arocas, 2011).

Por su parte, la reología permite determinar mediante métodos instrumentales una serie de parámetros objetivos directamente relacionados con las características sensoriales y subjetivas que definen la textura de un alimento. Por tanto, mediante el estudio de los parámetros reológicos de los alimentos se puede llegar a una valoración objetiva de su textura. Puesto que la textura engloba todas las propiedades mecánicas o parámetros reológicos perceptibles por los sentidos y pueden ser medidos mediante métodos objetivos instrumentales, es razonable que se apliquen dichos métodos para obtener rápidamente resultados precisos y reproducibles. No obstante, mediante la evaluación sensorial el ser humano es capaz de percibir, describir, cuantificar e integrar la totalidad de la textura, abarcando parámetros mecánicos, geométricos y de superficie, por lo que sería lógico pensar que el método más adecuado para su evaluación sea el análisis sensorial (Fernández, 2008).

Está claro que existe una relación estrecha entre el comportamiento reológico de los alimentos y su textura, por lo que el área de la tecnología de los alimentos ha dirigido durante bastante tiempo su interés hacia el desarrollo de métodos objetivos instrumentales para la medida de la textura (Pons y Fiszman, 1996). Entre los métodos que se han utilizado en la presente Tesis Doctoral se encuentran la penetración cónica, la extrusión inversa, los ensayos reológicos dinámicos y el análisis de perfil de textura.

Llegados a este punto, no cabe la menor duda sobre el hecho de que una clara comprensión de las propiedades reológicas y texturales de un alimento es fundamental en la investigación y desarrollo de nuevos productos (Steffe, 1996). Además, es muy importante poder correlacionar estas propiedades instrumentales de la textura con aquellas derivadas de la evaluación sensorial.

Las propiedades texturales y reológicas tienen una gran influencia sobre la preferencia y aceptación de los alimentos por los consumidores (Szczesnik y col., 1971; Szczesniak, 2002; Bourne, 2002), siendo especialmente importantes en el caso de los productos de patata recién elaborados y procesados (Fernández, 2008).

En el presente trabajo de investigación se ha optimizado la formulación del puré de patata mediante la adición de ingredientes funcionales mejorando así el valor nutricional de este producto alimenticio. Sin embargo, estos ingredientes afectan la textura del producto elaborado, por lo que el estudio de este atributo es fundamental para la obtención de un nuevo producto con una calidad final que garantice su aceptabilidad por parte del consumidor.

3.4 SITUACIÓN ACTUAL DEL ANÁLISIS SENSORIAL DESCRIPTIVO.

El análisis sensorial descriptivo es la herramienta más sofisticada y ampliamente utilizada entre todas las metodologías de las que disponen los profesionales sensoriales cuando se comparan con los métodos de aceptación y discriminación (Stone y Sidel, 2004; Varela y Ares, 2012).

Según Stone y Sidel (2004), el análisis descriptivo es una metodología sensorial que proporciona descripciones cuantitativas de los productos basados en las percepciones de un grupo de sujetos cualificados. Todos los métodos de análisis descriptivo implican la detección (discriminación) y descripción de aspectos sensoriales tanto cualitativos como cuantitativos de un producto. El número de jueces que normalmente participan en un ensayo descriptivo se sitúa entre ocho y veinte. La cualificación de dichos jueces implica una serie de etapas, de entre ellas puede considerarse más importante aquella que consiste en desarrollar un procedimiento de evaluación consensuado para determinar qué características sensoriales han de ser evaluadas y cómo debe realizarse dicha evaluación. Por otro lado, el rendimiento del panel debe ser controlado periódicamente en términos de poder de discriminación, acuerdo existente entre los miembros del panel y reproducibilidad para lograr resultados precisos y fiables (Valentín y col., 2012), además de detallados y consistentes en el tiempo (Moussaoui y Varela, 2010).

Desde el punto de vista de desarrollo de productos, la información descriptiva es esencial para centrarse en aquellas características identificadas como diferentes y poder establecer relaciones causales entre esas propiedades diferentes y el cambio o modificación de ingredientes o variables en el procesado del producto (Stone y Sidel, 2004). Este es uno de motivos por los que el perfil descriptivo de un producto se ha venido realizando de manera rutinaria por las industrias alimenticias para definir y cuantificar aquellas características sensoriales en las que los productos se diferencian; esta información tiene aplicaciones tales como la mejora y desarrollo de un producto, el control de calidad (Stone y Sidel, 1993; Lawless y Heymann, 2010), comprender las preferencias de consumidores (Greenhoff y MacFie, 1994) y relacionar esta información con datos obtenidos a partir de análisis instrumentales (Lee y col., 1999).

El análisis sensorial descriptivo convencional proporciona datos de muy buena calidad pero como contrapartida requiere de un extenso entrenamiento de los jueces en relación al vocabulario utilizado, antes de que estos puedan participar en un estudio como instrumento sensorial fidedigno. Además, debido a que el vocabulario y el entrenamiento han de ser adaptados a cada producto evaluado, para completar este análisis pueden requerirse desde semanas a meses (Valentín y col., 2012). Esto hace que las metodologías convencionales sean especialmente tediosas y complicadas de realizar. En empresas pequeñas este proceso conlleva un elevado gasto económico que a menudo no pueden sostener. Por el contrario, en las grandes empresas, capaces de acometer dicho gasto, surgen otros problemas como es la necesidad de invertir mucho tiempo ya que estas empresas a veces ofrecen un amplio rango de productos que requieren del trabajo paralelo de varios paneles. Además, la etapa de entrenamiento, que generalmente es bastante extensa, se consolida como otra gran desventaja para las empresas que quieren ofrecer una rápida respuesta en los mercados (Murray y col., 2001; Lawless y Heymann, 2010).

Por todas las vicisitudes mencionadas, es obvia la necesidad de métodos descriptivos más rápidos, efectivos, con menores costes económicos y más flexibles, de forma que se agilice la descripción sensorial de cada alimento nuevo que aparecerá en el mercado.

Como respuesta a estas demandas, en los últimos años se han desarrollado varias metodologías alternativas a los métodos tradicionales. Estas metodologías novedosas no requieren de fase de entrenamiento, pudiendo ser realizadas por sujetos con diferentes niveles de especialización que van desde jueces semientrenados hasta consumidores sin ningún tipo de experiencia en análisis sensorial, y que están resultando exitosos dado que son capaces de generar mapas sensoriales muy similares a aquellos obtenidos mediante la participación de jueces altamente entrenados (Varela y Ares, 2012). Estos métodos novedosos ofrecen a los miembros del panel la oportunidad de seleccionar sus propios atributos que identificarán características menos técnicas y más similares a las que un consumidor identificaría.

De esa manera, la información obtenida sobre la percepción que estos sujetos tienen de las características sensoriales de interés es más realista y fiable. Esta cuestión es particularmente importante para las empresas dedicadas a la alimentación ya que pueden lanzar al mercado productos que se corresponden con las percepciones y preferencias de los consumidores (Faye y col., 2006).

Tanto Husson y colaboradores (2001) como Worch y colaboradores (2010) han aconsejado que la utilización de estos métodos nuevos con la participación de consumidores es una buena alternativa a los métodos convencionales. Según estos autores, los perfiles sensoriales obtenidos con consumidores cumplen los requisitos de discriminación y reproducibilidad necesarios, siendo una alternativa interesante cuando las empresas tienen dificultades para utilizar paneles de jueces entrenados. Sin embargo, es importante enfatizar el hecho de que estos métodos más recientes no pueden ser considerados como sustitutivos de los métodos clásicos, ya que estos últimos son más exactos debido al extensivo entrenamiento que reciben los jueces; por lo tanto, los métodos nuevos han emergido más como un complemento a los métodos clásicos que como una sustitución.

El perfil sensorial de un alimento orienta a los participantes implicados en el desarrollo del mismo para poder realizar cambios que mejoren el producto, aproximándolo al perfil deseado por los consumidores. Por tanto, el conocimiento de la "composición deseada" de un producto permite la optimización del mismo y, por otro lado, son muy deseables en las industrias los modelos validados que relacionen las medidas sensoriales con las instrumentales (Murray y col., 2001).

Considerando todo lo mencionado, es vital que continúe la investigación sobre el análisis sensorial descriptivo, focalizando las ideas en los métodos más novedosos con la finalidad de que cambien las ideas tradicionales y se asegure un potencial óptimo de esta herramienta en el futuro.

3.4.1 PERFIL DE TEXTURA.

El método de Perfil de Textura fue desarrollado en los años sesenta por General Foods Corporation con el objetivo de definir los parámetros texturales de los alimentos (Skinner, 1988).

En un principio, Szczesniak (1963) desarrolló un sistema de clasificación de la textura el cual pretendía acercar la disparidad existente entre la terminología textural utilizada por los expertos y la utilizada por los consumidores, clasificando la textura percibida en tres grupos de características: mecánicas, geométricas y otras.

Posteriormente, este método fue ampliado por Civille y Szczesniak (1973) y Civille y Liska (1975) para considerar atributos específicos que describen productos concretos, incluyendo alimentos semisólidos, bebidas y otros productos no alimenticios.

El Perfil de Textura pretende describir la textura desde el primer bocado hasta la masticación completa del alimento considerando aspectos temporales de los atributos (Brandt y col., 1963).

Según Stone y Sidel (2004), este método representó avances en el análisis descriptivo desde un punto de vista estructural, es decir, en el desarrollo de la terminología descriptiva, las escalas para registrar las intensidades y las palabras o productos utilizados como extremos en cada categoría de la escala.

El objetivo de este método era eliminar los problemas derivados de la alta variabilidad individual de los sujetos participantes en el mismo, permitir la comparación directa de los resultados con materiales conocidos y proporcionar una correlación elevada con las medidas instrumentales (Szczesniak, 1963).

Los panelistas son seleccionados en base a su habilidad para discriminar las diferencias de textura en productos específicos conocidos para los que el panel se entrena (alimentos sólidos, semisólidos, bebidas, etc.) (Meilgaard y col., 2007). Estos últimos autores señalaron que para el entrenamiento, los panelistas evalúan una amplia variedad de productos de la misma categoría que el producto objeto de estudio, con la finalidad de proporcionar un amplio marco de referencia. Los panelistas definen todos los términos y todos los procedimientos para la evaluación, reduciéndose así la variabilidad encontrada en la mayoría de los análisis descriptivos.

La principal ventaja del Pefil de Textura es que a los panelistas se les enseñan los principios subyacentes de la textura, y esta experiencia de aprendizaje permite a los jueces evitar tediosas discusiones sobre términos redundantes y seleccionar los términos más apropiados técnicamente y más descriptivos para la evaluación de los productos (Meilgaard y col., 2007).

Un entrenamiento del panel tan extenso podría considerarse como una desventaja, sin embargo Otremba y colaboradores (2000) señalaron que conduce a una mayor coherencia y precisión por parte del panel.

3.4.2 ANÁLISIS CUANTITATIVO DESCRIPTIVO (QDA)

El análisis cuantitativo descriptivo fue desarrollado en el Departamento de Ciencia de los Alimentos de la Universidad de California en Davis. Según Murray y colaboradores (2001), el análisis cuantitativo descriptivo fue desarrollado durante los años 70 para tratar de subsanar en parte algunos de los problemas asociados con el Perfil de Textura (Stone y col., 1974; Stone y Sidel, 1993). Con frecuencia, los sujetos que participan en el análisis cuantitativo descriptivo (en inglés, Quantitative Descriptive Analysis, QDA) son previamente seleccionados de entre un grupo numeroso de candidatos, mediante cuestionarios dietéticos y los propios productos objeto de estudio, entendiéndose que los individuos que son consumidores frecuentes de dichos productos son más sensibles a las diferencias entre los mismos, y por tanto, más discriminativos

(Sawyer, 1962). El entrenamiento de los paneles para la evaluación sensorial mediante el método cuantitativo descriptivo requiere el uso de productos e ingredientes que sirven como referencia, al igual que se hace cuando se aplican otros métodos descriptivos, lo que ayuda a estimular la generación de terminología. Es importante tener en cuenta que el proceso para el desarrollo de vocabulario tiene que ser consistente aunque los panelistas son libres para desarrollar sus propios términos que posteriormente utilizarán para puntuar las muestras.

El método cuantitativo descriptivo está basado en el principio de habilidad de los panelistas para verbalizar las percepciones de un producto de una manera fidedigna; los jueces son seleccionados y entrenados en el reconocimiento de atributos y su posterior clasificación utilizando un lenguaje sensorial común y consensuado. Más tarde, los jueces puntúan los productos para obtener una descripción cuantitativa completa del producto en estudio (ASTM, 1992).

De cualquier manera, el lenguaje utilizado en este método no es técnico, sino más bien un lenguaje cotidiano, aunque los panelistas requieren de un cierto nivel de práctica para comprender el significado de los atributos. El análisis cuantitativo descriptivo asume que los jueces usarán diferentes partes de la escala para evaluar los atributos de los productos. Los diseños del análisis descriptivo están basados en medidas repetidas.

Una limitación del QDA es que es difícil comparar resultados entre paneles, entre laboratorios y espacios de tiempo diferentes (Murray y col., 2001). Por el contrario, el entrenamiento de los jueces para la aplicación de este método tiene una duración más breve que el requerido por otros métodos.

El análisis cuantitativo descriptivo ha supuesto un cambio significativo en la forma en la que los científicos sensoriales y los usuarios del análisis sensorial abordan la metodología descriptiva, gracias al uso de una escala gráfica que reduce el sesgo originado cuando se utilizan números en la clasificación, el tratamiento estadístico de los datos, la separación de los panelistas durante la evaluación y el enfoque gráfico que se utiliza para presentar los resultados.

3.4.3 FLASH PROFILE

El método Flash Profile (FP) fue sugerido para la descripción sensorial por Dairou y Sieffermann (2002), quienes lo definieron como una combinación original de la selección de términos mediante libre elección, junto con el método de ordenación basado en la presentación simultánea de todo el conjunto de productos estudiados.

En la práctica, las muestras codificadas son presentadas todas juntas a los jueces. En un primer paso, los panelistas tiene que analizarlas de forma comparativa con el objetivo de generar todos los descriptores que ellos consideren apropiados para la discriminación posterior de las muestras. En una segunda etapa, y para cada atributo generado, ellos ordenan todas las muestras de “poco” a “mucho”, de forma que los empates entre las muestras están también permitidos. Como en un perfil de libre elección, cada juez genera su propio conjunto de atributos de forma individual, los cuales tienen que ser lo suficientemente discriminantes como para permitir la ordenación de las muestras. En este método no se indica a los panelistas el número de atributos que deben generar (Dairou y Sieffermann, 2002; Delarue y Sieffermann, 2004; Lassoued y col., 2008; Moussaoui y Varela, 2010); sin embargo, sí son instruidos para que eviten utilizar términos hedónicos.

La comparación simultánea de todas las muestras permite una mejor discriminación del producto. Además, cuando las muestras analizadas pertenecen a la misma o similar categoría de producto, el FP puede ser más discriminativo que el perfil convencional (Mazzucheli y Guinard, 1999; Delarue y Sieffermann, 2004).

Entre las ventajas del Flash Profile destaca la de ser una herramienta rápida de mapeo sensorial, ser fácil de comprender por los panelistas, ser apropiada para aplicaciones en las que es necesaria una respuesta rápida, así como ser una herramienta inicial de búsqueda para un nuevo conjunto o categoría de productos y para estudiar un mercado específico (Dairou y Sieffermann, 2002; Delarue y Sieffermann, 2004; Tarea y col., 2007).

Una limitación del FP, siendo un método comparativo, es que el número de muestras que pueden ser evaluadas es limitado, y esto podría depender de la categoría de producto. Otra desventaja del Flash Profile es que cada juez crea su propia lista de atributos, y por lo tanto la interpretación semántica puede ser compleja (Dairou y Sieffermann, 2002; Veinand y col., 2011). Sin embargo, se ha probado que incluso aunque este método genera una gran cantidad de atributos diferentes, los más importantes o principales para la descripción de un conjunto de muestras están bien representados cuando se utiliza el FP, incluso cuando los consumidores hablan diferentes idiomas, lo que hace que este método sea especialmente idóneo para establecer comparaciones entre los resultados de diferentes países (Moussaoui y Varela, 2010).

Flash Profile ha sido utilizado para la descripción de diversos productos alimenticios como mermeladas de frutos rojos (Dairou y Sieffermann, 2002), productos lácteos de fruta (Delarue y Sieffermann, 2004), purés comerciales de manzanas y peras (Tarea y col., 2007), pan (Lassoued y col., 2008), bebidas calientes (Moussaoui y Varela, 2010), cuajada (Gómez Alvarado y col., 2010), tés fríos de limón (Veinand y col., 2011) y nuggets de pescado (Albert y col., 2011).

3.4.4 PROJECTIVE MAPPING & NAPPING®

Projective Mapping (PM), y su variante Napping®, son métodos de perfil que han sido desarrollados al objeto de reunir una configuración Euclidiana para cada juez en una única sesión sensorial (Pagès, 2005). Estos métodos fueron originalmente derivados de la psicología y previamente utilizados en investigaciones cualitativas de mercado para obtener asociaciones entre productos (Risvik y col., 1994; Pagès, 2005). PM fue propuesto para utilizarlo con consumidores, y junto con los resultados de un panel entrenado explicar la descripción del producto (Risvik y col., 1994).

Las muestras son simultáneamente presentadas a los panelistas, para ser posicionadas por cada juez en un espacio bidimensional como un "mantel" (la palabra "nappe" en francés, da origen al nombre Napping) o más a menudo en un folio A4 o A3 en blanco. Las muestras son colocadas por los participantes según las diferencias y similitudes entre ellas, de tal forma que cuánto más pequeña es la distancia que separa dos muestras, más similares son estas muestras (Perrin y col., 2008). El criterio para el posicionamiento de las muestras y su importancia son elegidas de forma individual por cada juez, lo que hace del Projective Mapping un procedimiento flexible y espontáneo (Moussaoui y Varela, 2010). El procesado simultáneo de todas estas configuraciones proporciona un resultado gráfico de todos los productos en el que dos productos están cercanos si ellos son percibidos de forma similar por todo el panel de jueces (Pagès, 2005).

Después del posicionamiento de las muestras, a veces se realiza un método conocido como Ultra Flash Profiling (Pagès, 2003; Perrin y col., 2008) que consiste en que los participantes en un Projective Mapping deben escribir directamente en el folio A3 o A4 los atributos que motivaron el posicionamiento de las muestras; de esta manera se obtiene una descripción de las diferencias y similitudes entre ellas.

Mediante el análisis estadístico multivariante de los datos, todos los mapas individuales son reunidos en una configuración consenso que junto con los comentarios o atributos generados podrían determinar el perfil sensorial del conjunto de muestras en términos de distancias y descripciones percibidas por el grupo de jueces.

Napping® es un método flexible que todavía hoy se está desarrollando para adaptarlo a diferentes objetivos dependiendo de la complejidad de los productos objeto de análisis. Está basado en la percepción global de las diferencias de un grupo de muestras, y puede considerarse como una forma natural e intuitiva de describir los productos por parte de los consumidores y que además es más cercana a lo que ocurre en el mercado real (Ares y col., 2011; Carrillo y col., 2012).

Napping® presenta la ventaja de ser bastante comprensible y fácil de realizar para los consumidores. Risvik y colaboradores (1997) incluso sugirieron la viabilidad de utilizarlo con niños dada la posibilidad de convertir el método en un juego. Sin embargo, Ares y colaboradores (2011) señalaron que para los consumidores noveles otras técnicas asimismo novedosas pueden resultar más fáciles de comprender y de llevarse a cabo que el propio Napping®.

Una desventaja del Napping es la limitación en el número de productos que pueden ser evaluados al mismo tiempo, y aunque va a depender mucho de las características sensoriales del producto, generalmente el máximo es de doce (Pagès, 2005). Otras limitaciones son la reproducibilidad, validación y robustez de los resultados que, como en la mayoría de las técnicas noveles, no se han estudiado todavía con suficiente detalle (Varela y Ares, 2012).

Esta metodología se ha aplicado para la evaluación sensorial de diversos productos alimenticios como sopas comerciales deshidratadas (Risvik y col., 1994), queso de leche de oveja (Bárcenas y col., 2004), zumo de cítricos (Nestrud y Lawless, 2008), chocolate (Kennedy y col., 2009), barritas (King y col., 1998; Kennedy, 2010), vinos (Perrin y Pagès, 2009), bebidas calientes (Moussaoui y Varela, 2010), manzana y queso (Nestrud y Lawless, 2010), postres lácteos (Ares y col., 2010), bebidas en polvo (Ares y col., 2011) y nuggets de pescado (Albert y col., 2011).

3.5 REFERENCIAS BIBLIOGRÁFICAS

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CAPÍTULO 4

TRABAJOS EXPERIMENTALES

TEXTURE OF EXTRA VIRGIN OLIVE OIL-ENRICHED MASHED POTATOES: SENSORY, INSTRUMENTAL AND STRUCTURAL RELATIONSHIPS.

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ABSTRACT

The aim of this work was to study the effect of the addition of extra virgin olive oil (EVOO) on instrumental textural properties, sensory texture profile analysis (TPA) and microstructure of fresh and frozen/thawed mashed potatoes formulated without and with added cryoprotectants [kappa-carrageenan (κ-C) and xanthan gum (XG)]. EVOO behaves as soft filler due to droplet aggregates, whereas addition of cryoprotectants led to more structured mashed potatoes (MP) thanks to the gelling properties of κ-C. Both the percentage of added EVOO and processing had a much less significant effect on the texture of the MP containing κ-C and XG, evidencing the ability of this biopolymer blend to impart freeze/thaw stability. All samples with added EVOO were perceived as significantly softer and creamier than the samples without EVOO, whereas all MP samples with added cryoprotectants were perceived as significantly thicker and creamier than those without hydrocolloids.

KEYWORDS

Extra virgin olive oil, freezing, mashed potatoes, microstructure, texture, TPA sensory attributes

PRACTICAL APPLICATIONS

Previous studies showed that the quality after freezing and thawing may be improved by the addition of 1.5 g/kg of kappa-carrageenan and 1.5 g/kg of xanthan gum, and/or incorporation of dietary fiber, improvement of mashed potatoes texture by retarding starch retrogradation and increasing water-holding capacity. Growing awareness of the link between diet and health is fast changing consumer habits, so that there has been increasing demand for foods with health enhancing properties. Extra virgin olive oil (EVOO) has important nutritional characteristics linked to its biophenol content and has very important antioxidant properties. The results have shown that although instrumental textural data were able to explain differences in consistency perceived, structural information is needed to understand differences in creaminess. Back extrusion test is recommended to industry as practical quality control tool in the commercial production of mashed potatoes with added EVOO.

INTRODUCTION

Various health organizations recommend a daily intake of around 600 g of fruit and vegetables, but few people manage to consume this amount. Led by consumer demand, the food industry has shown an increased interest in the manufacture of healthier and more natural fruit and vegetable food products, such as soups, drinks and sauces (Whybrow *et al*. 2006). Mashed potatoes (MP) made from 100 % fresh potato tubers are, in addition, a natural vegetable semisolid food, which may also be suitable for freezing as a ready-meal component or as a product in itself such as potato gratin (Alvarez *et al*. 2009).

Olive oil is an important component of the diet of the countries surrounding the Mediterranean Sea. Because of its composition, olive oil is a good source of biophenols (Boskou and Visioli 2003) as well as lipid-soluble and water-soluble vitamins (tocopherols, β-carotene, ascorbic acid). In addition, thanks to its balanced fatty acid composition virgin olive oil has highly appreciated nutritional characteristics (Mildner-Szkudlarz and Jeleń 2010), known for a long time to the people of the Mediterranean region, who use it daily for a variety of culinary purposes. Biophenols with important antioxidant properties and a role in atherogenesis and cancer have been found and quantified in virgin and extra virgin olive oils (EVOOs; Muniz 2007). However, consumption has also increased in non-Mediterranean areas thanks to growing interest in the Mediterranean diet and a belief that it prevents certain diseases (Boskou and Visioli 2003; Paraskevopoulou *et al*. 2005). A classic white sauce usually contains flour, milk and butter, but olive oil has been added to a white model-sauce to produce an innovative sauce approximating "Mediterranean cooking" (Mandala *et al*. 2004).

The oil volume fraction exerts profound effects on the physicochemical and viscoelastic properties of emulsions, such as droplet size distribution, creaming, oxidative stability and rheology (Dickinson and Chen 1999). Fat droplets influence the overall physicochemical and sensory properties of foods in a variety of different ways (Chantrapornchai *et al*. 1999). A great deal of research has been done on the influence of fat droplets on the rheology, stability and flavour of food emulsions, but less is known about their influence on emulsion appearance. Color is one of the major attributes affecting consumer perception of the quality of virgin olive oil (Criado *et al*. 2008), and chloroplast pigments (chlorophyll and carotenoids) are mainly responsible for the color of virgin olive oil, ranging from yellow–green to greenish gold (Ayuso *et al*. 2004).

Texture is by far the most important quality criterion for consumer sensory acceptance of freshly prepared and processed potato products, and particularly of frozen/thawed and dehydrated MPs. A fluffy and medium-consistency texture is desirable, whereas pastiness, gumminess and stickiness are negative attributes (Lamberti *et al*. 2004). Texture instability remains the most significant challenge for frozen food products, especially with inevitable post-production temperature fluctuations. Loss of moisture and changes in textural attributes often result in significant reduction of product quality.

Previous studies showed that the addition of kappa-carageenan (κ-C) and xanthan gum (XG) to MP at a low concentration (each cryoprotectant at 1.5 g/kg) is recommendable on the basis of overall acceptability, especially when the product is going to be frozen (Alvarez *et al*. 2009; Fernández *et al*. 2009). κ-C provides the appropriate texture, while XG imparts creaminess and mouthfeel to the product.

No research has been done on the addition of olive oil in fresh and frozen/thawed mashed potatoes (designated FMP and F/TMP, respectively), particularly with EVOO. The use of EVOO rather than commercial olive oil is preferable because of its high concentrations of both unsaturated fatty acids and antioxidant compounds such as polyphenols and tocopherols (Severini *et al*. 2003). The purpose of the present research was to evaluate the effects of adding EVOO on the textural, physical, structural and sensory characteristics of FMP and F/TMP formulated without and with added cryoprotectants.

MATERIALS AND METHODS

Materials

The potatoes used were fresh tubers (cv Kennebec) from Aguilar de Campoo (Burgos, Spain) grown in 2008. κ-C (GENULACTA carrageenan type LP-60) and XG (Keltrol F [E]) were donated by Premium Ingredients, S.L. (Girona, Spain). EVOO (Carbonell, Sevilla, Spain) was chosen for addition to the MP. Following range-finding experiments, the lower and upper levels of EVOO to be used were set at 10 and 50 g/kg, respectively. A sample without EVOO was also prepared for each type of MP and processing conditions.

Preparation of MP Samples

Tubers were manually washed, peeled and diced. MP were prepared in ~ 2000 g batches from 607.7 g/kg of potatoes, 230.8 g/kg of semi-skimmed in-bottle sterilized milk (fat content, 15.5 g/kg), 153.8 g/kg of water, 7.7 g/kg of salt (NaCl) and the corresponding EVOO concentration (0, 10, 25 and 50 g/kg) using a TM 31 food processor (Vorwerk España, M.S.L., S.C., Madrid, Spain). MPs were prepared without and with added κ-C and XG (MPA and MPB samples, respectively). In the latter case, hydrocolloids (each at 1.5 g/kg) were also added to the rest of the ingredients in the form of a dry powder. All the ingredients were cooked for 35 min at 90C (blade speed: 40 rpm) (Alvarez *et al*. 2009; Fernández *et al*. 2009). The mash was ground for 40 s (1,200 rpm) and for 20 s (2,600 rpm). The product was at once homogenized through a stainless steel sieve (diameter: 1.5 mm). The highest EVOO concentration was added twice to the MP to evaluate the effect of order of addition and EVOO thermal treatment on MP quality. First, 50 g/kg of EVOO was added along with the rest of the ingredients as indicated above, whereas in the second case the same EVOO concentration (designated "50b" g/kg) was added to the MP before final homogenization. Half of each fresh blend (FMP samples) was analysed immediately and the other half was frozen and thawed (F/TMP samples). Two repetitions of each composition were prepared in different weeks.

Freezing, Thawing and Heating Procedures

MP samples were placed on flat-freezing and microwave-thawing trays, and then frozen by forced convection with liquid nitrogen vapour in an Instron programmable chamber (model 3119-05, −70/+250C) at −60C until their thermal centres reached −24C (Fernández *et al*. 2009). After freezing, the samples were packed in polyethylene plastic bags, sealed under light vacuum (–0.05 MPa) on a Multivac packing machine (Sepp Haggenmüller KG, Wolfertschwenden, Germany), and placed in a domestic freezer for storage at −24C. Packed frozen samples were thawed in a Samsung M1712N microwave oven (Samsung Electronics S.A., Madrid, Spain). Samples were heated for 20 min at an output power rating of 600 W. Samples were brought up to 55C by placing them in a Hetofrig CB60VS water bath (Heto Lab Equipment A/S, Birker□d, Denmark). Sample testing was 55C, where water and product temperatures were monitored by T-type thermocouples as described elsewhere (Alvarez *et al*. 2005, 2008, 2009; Fernández *et al*. 2008).

Instrumental Texture Measurements

Back extrusion (BE) and cone penetration (CP) mechanical tests were performed in order to study the empirical rheological behavior of "semisolid like" samples. Both experiments were performed using a TA.HDPlus Texture Analyser (Stable Micro Systems Ltd, Godalming, UK) equipped with a 300 N load cell. During tests, MP samples were kept at 55C by means of a Temperature Controlled Peltier Cabinet (XT/PC) coupled to a separate heat exchanger and proportional-integral-derivative control unit. For performance of BE tests, a rig (model A/BE, Stable Micro Systems) was used consisting of a flat 45 mm diameter perspex disc plunger that was driven into a larger perspex cylinder sample holder (50 mm diameter) to force down into the MP samples and flow it upward through the concentric annular space between plunger and the container. The measuring cup was filled with 50 ± 1 g of MP. Product was extruded to a distance of 20 mm at 2 mm/s compression rate. At this point (most likely to be the maximum force), the probe returns to its original position. From the recorded force-time curves, texture parameters with physical meaning are calculated, which vary from simple consistency indices to a derived flow behavior index, which is obtained according to the mathematical model suggested by Osorio and Steffe (1987). In this study, maximum positive force of extrusion (firmness (N)) and the negative area of extrusion (viscosity index (N·s)) have been taken into account in order to describe texture changing in MP samples. For performing the CP tests, a Texture Technologies Corporation spreadability rig (HDP/SR, Stable Micro Systems) was used, consisting of a 45° conical perspex probe (P/45 C) that penetrated a conical sample holder containing 7 ± 0.1 g of MP product. Product was penetrated to a distance of 17.5 mm at 3 mm/s compression rate. CP work per displaced volume (J/m^3) required to accomplish penetration was calculated from the area under the curve up to the "peak" or maximum penetration force, and the average force of the complete curve (N) was also recorded. Texture measurements were performed in quadruplicate and results averaged.

Other Quality Parameters

The color of the MP in the pots was measured with a Hunter-Lab model D25 (Reston, VA) color difference meter fitted with a 5 cm diameter aperture. Results were expressed in accordance with the CIELAB system with reference to illuminant D65 and a visual angle of 10°. The parameters determined were L^*, a^* and b^*. A higher L^* value indicated a brighter or whiter sample and values of a^* and b^* indicated red-green and yellow-blue colors. Yellowness index (YI) was calculated as $142.86b^*/L^*$ (Fernández *et al*. 2008).

Expressible water (E_w) was measured by centrifugal force. Centrifuge tubes containing approximately 10 g of MP were centrifuged at 15,000×g for 30 min in a Sorvall®, RC-5B apparatus (Global Medical Instrumentation, Inc, Clearwater, MN). E_w

was expressed as the percentage of liquid separated per total weight of sample in the centrifuge tube (Eliasson and Kim 1992). Measurements of color and E_w were performed in quadruplicate and the results averaged.

Sensory Analyses

MP samples were subjected to texture profile analysis (TPA) modified to evaluate vegetables purees according to UNE 87025 (1996), which was used to select and define the sensory attributes included in the profile. A panel of 4 assessors, previously trained according to the ISO guidelines (ISO 8586-1 1993) and with specific exercise in MP for 8 years (Alvarez *et al*. 2005, 2008; Fernández *et al*. 2008), evaluated the textural attributes of the samples. Profile attributes were classified into four groups (Alvarez *et al*. 2008). Attributes are listed in the order of the perception according to ISO guidelines (ISO 13299 2003): attributes perceived before putting the sample in mouth (granularity and moisture [1]); attributes perceived at the time of putting the sample in the mouth (stickiness, denseness, homogeneity, moisture [2] and firmness); attributes perceived at the time of preparing the sample in the mouth for swallowing (cohesiveness, adhesiveness and fibrousness [1]); attributes perceived during final and residual phases of mastication (ease of swallowing, palate coating and fibrousness [2]). Thereby, for moisture and fibrousness, numbers in brackets [1] and [2] refer to the order of their perception in the mastication process. A description of the sensory attributes evaluated during the TPA can be found elsewhere (Alvarez *et al*. 2008).

Samples were evaluated, in duplicate, in morning sessions (11:00 a.m.-1:00 p.m.). Daily for 40 days, assessors were given four samples (about 20 g each), for scoring attributes of each group in the texture profile. All the samples were served at 55 ± 1C on Petri dishes. This sample temperature was reached and kept constant by placing the product in the Hetofrig CB60VS water bath prior to testing. For each sample, panelists evaluated the perceived intensity of the 13 attributes on 8 cm descriptive linear scales labeled at each anchor: (left anchor: 1 = ‘‘not detectable”; right anchor: 9 = ‘‘extremely intense’’). To reduce fatigue a rest period of 5 min was taken after scoring each sample.

MP samples were also subjected to an overall acceptability (OA) test based on all sensory attributes (texture, color, taste) on a 9-point hedonic scale (with 8 cm) labelled at each anchor: (left anchor: 1 = “dislike extremely”; right anchor: 9 = “like extremely”). In this case, sensory assessment was conducted by a 14-member untrained panel. Every day, one sample (about 20 g each) was served under the same conditions as indicated above.

Scanning Electron Microscopy (SEM)

MP microstructure was examined by SEM using a Hitachi model S-2.100 microscope (Hitachi Ltd., Tokyo, Japan) National Center For Metallurgical Research (CENIM-CSIC). MP samples were air-dried, then mounted and sputter-coated with Au (200 A aprox.) in a SPI diode sputtering system metallizer. Photomicrographs were taken with a digital system Scanvision 1.2 of Röntgenanalysen-Technik (800x1.200 pixel, Rontec, GmbH, Berlin, Germany).

Statistical Analysis

A three-way analysis of variance (ANOVA) with interactions was applied to evaluate how the three factors studied—EVOO concentration, presence or absence of hydrocolloids and performance or not of processing —affected the texture, color, sensory attributes and the OA of the MP. E_w was always zero for the MPB samples; a two-way ANOVA with interactions was applied to evaluate how EVOO concentration and processing affected the E_w of the products. Minimum significant differences were calculated using Fisher's least significant difference test (99% for comparison of instrumental parameters and 95% for comparison of sensory attributes and OA). Analyses were performed with Statgraphics® software version 5.0 (STSC Inc., Rockville, MD).

RESULTS AND DISCUSSION

Instrumental Texture Measurements

Table 1 shows the effects of EVOO concentration, cryoprotectant addition and processing on the values of the textural properties derived from the BE and CP tests. Samples with added *κ*-C and XG, as well as those subjected to freezing/thawing, presented significantly higher and lower textural properties than their respective counterparts. Previous studies showed that when *κ*-C/XG blends were added to FMP and F/TMP samples, *κ*-C provided the appropriate texture whereas XG imparted creaminess to the product (Alvarez *et al*. 2009; Fernández *et al*. 2009; Alvarez *et al*. in press). Analogously, in starch/XG blends, it was observed that XG does not interfere in potato starch network building (Mandala and Palogou (2003); Mandala *et al*. 2004). Therefore, addition of both hydrocolloids to MP produces a more structured system which is associated with the gelling properties of *κ*-C. In natural MP, the product was softer than the fresh control after freezing and thawing (Alvarez *et al*. 2005). MP is a starchy food, and as such may present quality problems such as syneresis and organoleptic and textural changes. These problems have been ascribed to phase separation caused by retrogradation of the starch (Eliasson and Kim 1992; Kim and Eliasson 1993).

With respect to the effect of EVOO addition, the maximum textural property values were registered in the samples without EVOO, although differences between textural properties of samples with 10 g/kg added EVOO and those without EVOO were non-significant (Table 1). However, increasing EVOO concentration produced softer, liquid-like systems, indicating that EVOO behave as soft filler. This result is to be expected as increasing concentrations of liquid oil are added to the product, increasing the oil-phase volume fraction. In oil-in-water emulsions, the extent of the linear region decreased with increasing oil-phase volume fraction from 20 to 40% v/v (Sun and Gunasekaran 2009). For their part, Dickinson and Chen (1999) suggested that oil/water emulsions may undergo a behaviour transition from predominantly enthalpic behaviour, with increasing oil-phase volume fraction.

The ANOVA also showed that the three binary interactions had a significant effect on instrumental firmness, work per displaced volume and average force (Table 1). This means that the effect of EVOO concentration on the texture depended on the presence of κ-C and XG and on the freezing/thawing of the systems. Besides, EVOO concentration and cryoprotectant addition (AB) and cryoprotectant addition and processing (BC) interactions also significantly affected the viscosity index from the BE tests.

TABLE 1. EFFECTS OF EVOO CONCENTRATION, CRYOPROTECTANT ADDITION AND FREEZING/THAWING ON TEXTURAL PROPERTIES OF MP

Source	Firmness (N)	Viscosity index (N s)	Work per displaced volume (J/m³)	Average force (N)
Main effects:				
A:EVOO concentration (g/kg)				
0	6.21 a	-29.33 a	3518.78 a	1.51 a
10	6.08 a	-28.37 a	3462.25 a	1.49 a
25	5.32 b	-26.12 b	2867.16 b	1.23 b
50	4.69 c	-23.06 c	2681.10 b	1.15 b
50b	4.74 c	-23.69 c	2786.29 b	1.19 b
P values	<0.001	<0.001	<0.001	<0.001
LSD (99%)	*0.26*	*1.24*	*227.00*	*0.097*
B:Cryoprotectant addition				
Without *κ*-C and XG	4.71 a	-20.71 a	2333.51 a	1.00 a
With *κ*-C and XG	6.10 b	-31.52 b	3792.72 b	1.63 b
P values	<0.001	<0.001	<0.001	<0.001
LSD (99%)	*0.16*	*0.78*	*143.57*	*0.06*
C:Processing				
Fresh	5.62 a	-26.73 a	3248.00 a	1.39 a
Frozen/thawed	5.19 b	-25.50 b	2878.23 b	1.23 b
P values	<0.001	<0.001	<0.001	<0.001
LSD (99%)	*0.16*	*0.78*	*143.57*	*0.06*
Interactions				
AB	<0.001	<0.001	<0.001	<0.001
AC	0.001	0.18	<0.001	<0.001
BC	<0.001	<0.001	<0.001	<0.001
ABC	<0.001	<0.001	<0.001	<0.001

EVOO, extra virgin olive oil; LSD, least significant difference; MP, mashed potato.

From the variation in the firmness value based on EVOO concentration for both MPA and MPB samples shown in Fig. 1A, one can observe that firmness was lower in the MPA than in the MPB samples; moreover, the variation in sample firmness was much greater when EVOO content increased from 10 to 50 g/kg in the MPA samples than in the MPB ones. Also, when the concentration of added EVOO was increased, the firmness value behaved similarly in the FMP and F/TMP samples (Fig. 1B); in both cases, the increase in EVOO content led to reduced firmness, without important differences between 50 and 50b g/kg. As droplet concentration increases, the droplets are polydispersed and the samples present a less close packing structure. In mayonnaise, increasing walnut oil content increases the diameter of oil droplets and consequently reduces viscoelastic properties (Cavella *et al*. 2009). From the variation in the firmness based on processing, the firmness value developed differently for the MPA and MPB samples (Fig. 1C). Processing significantly reduced sample firmness in the MPA samples but significantly increased it in MPB samples. This behaviour can be explained taking account that much stronger and more cohesive networks are formed when solutions of XG are frozen and thawed (Giannouli and Morris 2003). The effect of XG may be explained by amylose/XG interactions, which compete against amylose/amylose interactions, retarding or even preventing retrogradation. Also, the addition of small amounts of XG to white sauces made with starches from different sources significantly improves freeze/thaw stability (Arocas *et al*. 2009).

In turn, the variation in average force with EVOO concentration for both MPA and MPB samples (Fig. 1D) was similar to that observed in firmness. In this case of the MPB samples, the ones with 25 g/kg EVOO added had poorer consistency, whereas in the MPA systems, the ones with 50 g/kg had poorer consistency. When the EVOO concentration was increased the average force decreased in both FMP and F/TMP samples (Fig. 1E), although in the latter case adding 10 g/kg EVOO slightly increased the average force as compared with the control without EVOO. Both the BE firmness and the CP average force values were greater when the EVOO was added after cooking (50b g/kg) in the FMP samples but not in the F/TMP samples. When the processing-dependent variation in average force was plotted (Fig. 1F), the changes in that value were also similar to those observed for firmness (Fig. 1C). Plots for the viscosity index and the work per displaced volume have been omitted for the sake of brevity.

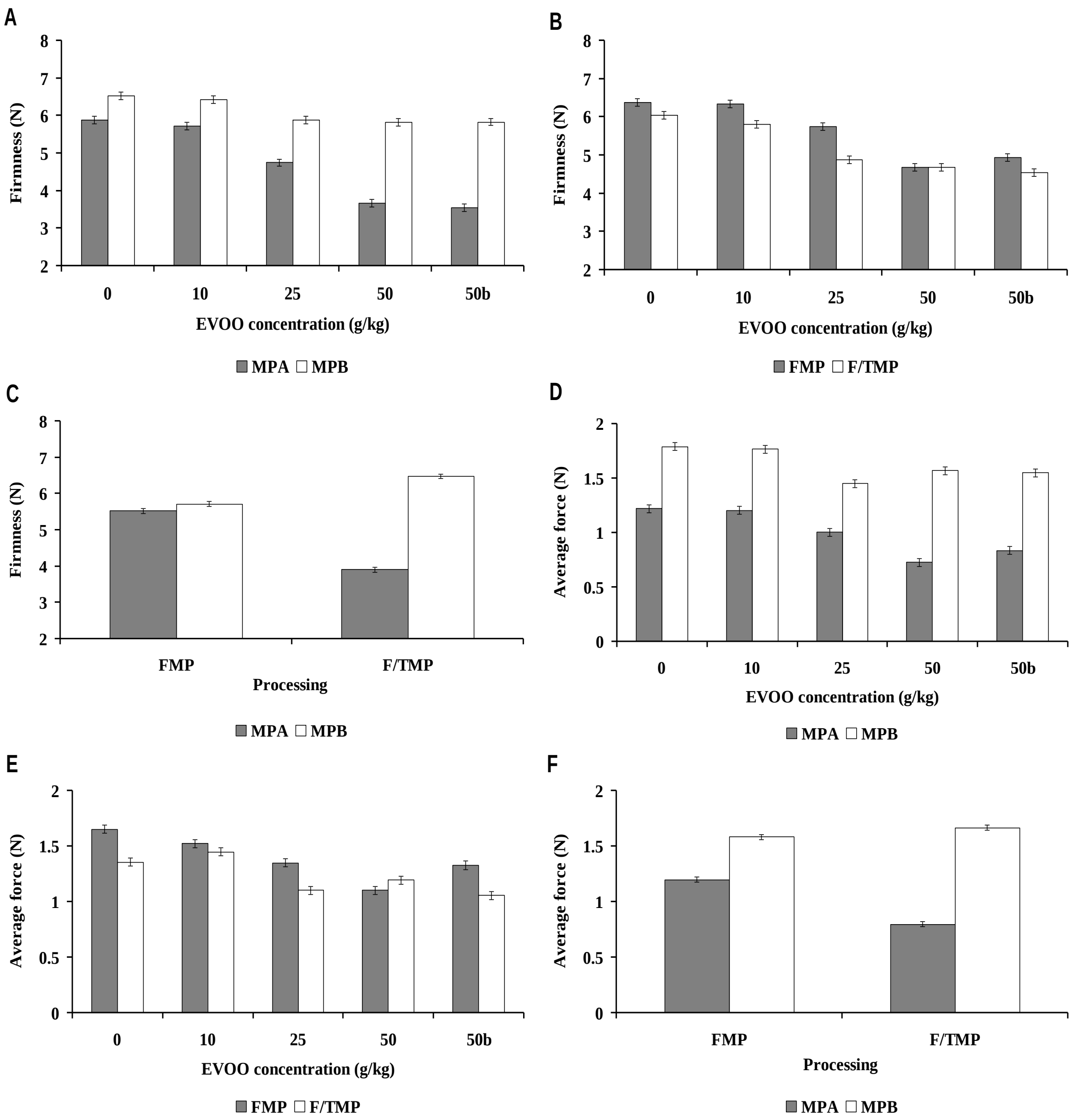

FIG. 1. TEXTURAL PROPERTIES OF MASHED POTATOES WITH ADDED EXTRA VIRGIN OLIVE OIL (EVOO)

(A-C) Firmness; (D-F) Average force; MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively.

Color Measurements and Expressible Water

All the three factors studied significantly changed the color parameters, although processing did not significantly affect the yellowness index (YI) (Table 2). An increase in EVOO level favours higher *L** value (lightness) due to an increase in the overall light scattering associated with the scattering properties of fat (Chantrapornchai *et al*. 1999). As the EVOO concentration increased there was an increase in redness (decreasingly negative *a** values) and in yellowness (YI), associated with the augmented pigment content of the MP. The pigment profile of the virgin olive oil comprises chlorophyll a, chlorophyll b, and derivative pigments associated with the acidic medium of the oil extraction process (Criado *et al*. 2008).

*L** increased when *κ*-C and XG were added to the MP, which could be partially due to their absolute water-holding capacity (WHC) as discussed below. Also, *a** was higher in the MPB than in the MPA samples, indicating significant raised sample redness. The loss of greenness associated with cryoprotectant addition was probably due to the presence of XG in the system as found previously (Fernández *et al*. 2008). Increased lightness in the F/TMP samples as compared to their FTM counterparts may have been partly due to the formation of fissures produced by the growth of ice crystals during freezing, which favours the release of water; this would transmit the light more rather than capturing it. For its part the loss of greenness found in the processed samples (*a** values nearer to 0) as compared to the fresh counterparts could be due to slight non-enzymatic browning (Maillard reaction) during microwave thawing.

On the other hand, the three interactions had a significant effect on *L** and YI (Table 2). Moreover, AB and EVOO concentration and processing (AC) interactions significantly affected the *a** value. The variation in the *L** value based on EVOO concentration in both MPA and MPB samples (Fig. 2A) shows that increased EVOO concentration produced an increase in the $L*$ value in both samples. The influence of droplet characteristics on the optical properties of colored oil-in-water emulsions has been studied (Chantrapornchai *et al*. 1999). The lightness of the emulsions increased with increasing droplet concentration and decreasing droplet size. As the droplet concentration increases so does the reflectance because the droplets scatter light more effectively and hence the light beam is unable to penetrate further into the product and be absorbed.

TABLE 2. EFFECTS OF EVOO CONCENTRATION, CRYOPROTECTANT ADDITION AND FREEZING/THAWING ON COLOR MEASUREMENTS AND EXPRESSIBLE WATER OF MP

Source	$L*$	$a*$	YI	E_w (%)
Main effects:				
A:EVOO concentration (g/kg)				
0	60.79 a	-3.85 a	10.14 a	22.42 b
10	62.95 b	-3.70 b	13.73 b	25.73 a
25	63.68 c	-3.54 c	18.58 c	20.72 d
50	66.04 d	-3.11 d	24.08 d	21.52 c
50b	65.70 e	-3.14 d	23.47 e	21.85 b, c
P values	<0.001	<0.001	<0.001	<0.001
LSD (99%)	*0.07*	*0.02*	*0.20*	*0.71*
B:Cryoprotectant addition				
Without κ-C and XG	62.85 a	-3.59 a	16.74 a	-
With κ-C and XG	64.81 b	-3.34 b	19.26 b	-
P values	<0.001	<0.001	<0.001	-
LSD (99%)	*0.04*	*0.01*	*0.13*	-
C:Processing				
Fresh	63.33 a	-3.53 a	18.03 a	21.01 a
Frozen/thawed	64.33 b	-3.40 b	17.97 a	23.89 b
P values	<0.001	<0.001	0.17	<0.001
LSD (99%)	*0.04*	*0.01*	*0.13*	*0.45*
Interactions				
AB	<0.001	<0.001	<0.001	-
AC	<0.001	<0.001	<0.001	<0.001
BC	<0.001	0.34	<0.001	-
ABC	<0.001	<0.001	<0.001	-

EVOO, extra virgin olive oil; LSD, least significant difference; MP, mashed potato.

The differences between the *L** values of the MPA samples and their MPB counterparts increased with increasing the EVOO content (Fig. 2A). In emulsions, XG is added to the aqueous phase to prevent droplets from rapidly creaming and coalescence (Parker *et al*. 1995; Sun and Gunasekaran 2009). In this study oil droplet diameters were not measured, but it is probable that the droplets in the MPB samples were smaller than in the ones without cryoprotectants as the presence of XG in the system would prevent coalescence. The reason why the *L** values were lower in the MPA samples, then, is that reflectance decreases with increasing droplet diameter. Note that in the MPB samples the *L** value was greater when the EVOO was added after cooking (50b g/kg), whereas in the MPA systems it was greater in the samples with 50 g/kg EVOO added before cooking. This discrepancy could also be related to the presence of cryoprotectants in the system. MP with EVOO added before final homogenization would be expected to have larger droplets because the oil was not thoroughly triturated. In the presence of XG, the droplets scatter light more effectively when the oil is not so strongly entrapped in the matrix. In the MPA samples on the other hand, reflectance probably decreased because the scattering efficiency of the droplets decreases above a certain droplet size (Chantrapornchai *et al*. 1999).

In turn, as the droplet concentration increases, more reflected light travels through the oil phase of the MP being absorbed by the pigments mentioned earlier, intensifying the color of the MP (Figs. 2B, C). However, as regards YI values, there were small differences between FMP and F/TMP samples. Anyway, the color differences found between samples, although significant, should not be of major importance in practical terms.

E_w changed significantly with EVOO concentration and processing (Table 2), and the AC interaction had a significant effect on the WHC of the samples (Fig. 2d). In this study, addition of κ-C and XG reduced the E_w of both FMP and F/TMP samples to 0%, corroborating the well-established ability of XG to reduce water separation (Alvarez *et al*. 2008, 2009; Arocas *et al*. 2009), and evidencing the existence of XG-water or XG-water-XG interactions in the systems. XG is an anionic, hygroscopic material of exceptional pseudoplasticity (Baranowska *et al*. 2008); its texturizing effect can be achieved at low gum concentration because of unusual water-holding ability. Also, adding XG (0.3% w/w) to corn starch pastes (10% w/w) minimized amylose retrogradation, syneresis and rheological changes after freezing (Ferrero *et al*. 1994). Certainly, the E_w values confirm that XG effectively stabilizes MP against syneresis when no more than 1.5 g/kg is added.

Besides, WHC was greater in the FMP samples than in their F/TMP counterparts at all EVOO concentrations (Fig. 2d). This result is probably related to structural damage caused by freezing. The addition of EVOO at low concentrations significantly increased E_w, mainly in the processed samples, which is likely due to that the interchain spaces were occupied by oil, displacing the water (Liehr and Kuliche 1996). However, the addition of EVOO at higher concentrations significantly reduced water loss, probably because excess oil hindered the release of water from the starch matrix. EVOO by itself was not effective in enhancing the WHC of MP. In any case E_w percentages were also quite high (> 20) in both FMP and F/TMP samples without added EVOO, evidencing the presence of weak starch-water or starch-water-starch interactions in all the systems. Water separation in the MPA samples is related to starch retrogradation and consequent reduction of WHC (BeMiller and Whistler 1996).

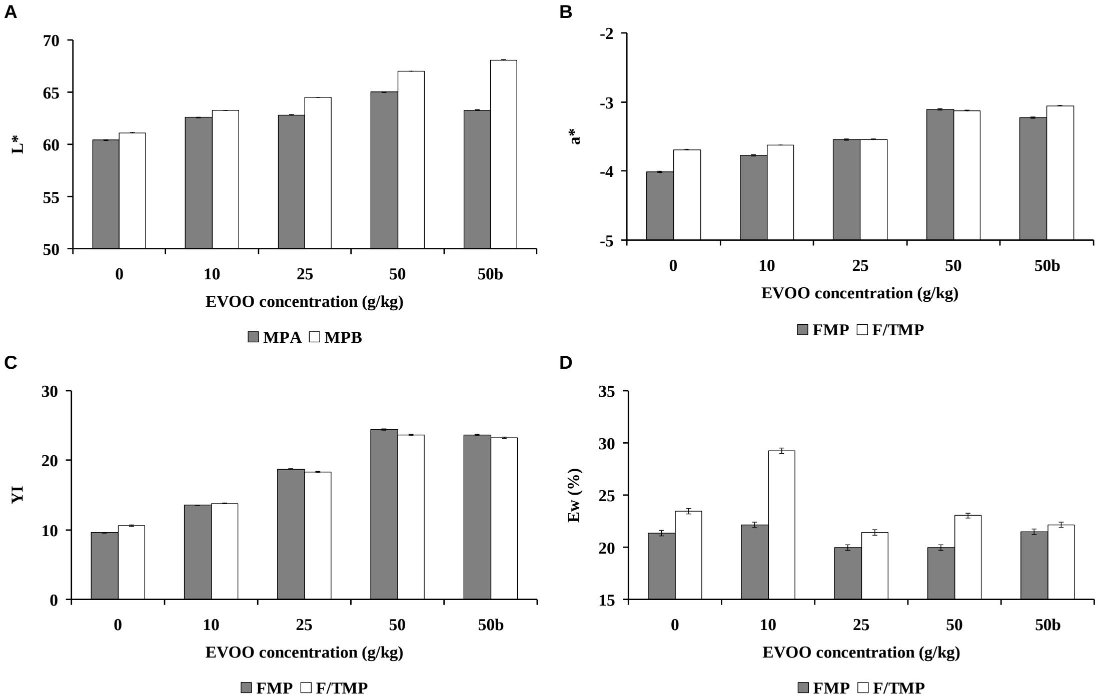

FIG. 2. COLOR PARAMETERS AND EXPRESSIBLE WATER O FMASHED POTATOES WITH ADDED EXTRA VIRGIN OLIVE OIL (EVOO).

(A-C) *L, lightness; *a**, red-greenness; YI, yellowness index; (D) E_w, expressible water; MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively.**

Sensory Analyses

Attributes perceived before putting the sample in mouth. All the three main factors and their interactions significantly (P < 0.05) affected the scores for granularity and moisture (1) (Table 3). One can observe that at all EVOO concentrations granularity scores were greater in the MPA samples (Fig. 3A) and likewise in the fresh products (Fig. 3B). Christianson *et al*. (1981) indicated that gums like XG affect the gelatinization and retrogradation of starch through strong associations with amylose, resulting in reduced amylose-amylose interactions. In turn, presence of XG reduced granularity in the F/TMP systems by assisting new starch/water interactions and consequent water absorption. In both MPA and MPB samples, panelists judged granularity lowest in the samples with more than 10 g/kg added EVOO. The effects of

EVOO on granularity are related to the lubricating and coating properties conferred by the oil as reported for vanilla custard desserts (De wijk *et al*. 2003).

In turn, moisture (1) decreased significantly with respect to MPA samples with the addition of cryoprotectants in both FMP and F/TMP (Fig. 3C). Panelists detected greater ability to hold water molecules in MPB samples, confirming the results for E_w values. Similarly, panelists detected less aqueousness in the processed samples than in the fresh ones, probably due to water loss.

Attributes perceived at the time of putting the sample in the mouth. Stickiness scores were significantly higher in the MPB samples, although there were no differences in these scores as a consequence of EVOO concentration or processing (Table 3; Fig. 3D). In turn, the three factors significantly affected scores for denseness, homogeneity, moisture (2) and firmness. Denseness was significantly higher in the processed than in the fresh samples only when EVOO was added at the highest concentrations (Fig. 3E). Also, denseness was lower in the MPA than in the MPB samples (Fig. 3F), and only in this latter case were denseness scores significantly higher in the F/TMP samples than in their FMP counterparts.

When EVOO concentration was increased, homogeneity increased in both MPA and MPB samples (Fig. 3G). Note that the presence of EVOO in the systems rendered differences in homogeneity among MPA and MPB samples less appreciable. Also, when EVOO concentration was increased (Fig. 3H), homogeneity increased in the FMP products but was almost constant in the processed samples. This indicates a positive effect of adding EVOO to MP, since the negative effect of freezing on this attribute is masked by the oil. Panelists detected reduced moisture (2) in the MPB samples and in the processed systems, and when the EVOO concentration was increased, moisture (2) significantly increased when cryoprotectants were also added (Fig. 3I).

In turn, panelists detected reduced firmness in the samples with added EVOO, without added cryoprotectants and without processing. One can observe that the processed samples with the lower and higher EVOO concentrations were the firmest, whereas in the systems with 25 g kg^{-1} added EVOO the fresh samples had similar firmness than the control (Fig. 4A). In the MPA samples there were no differences between firmness scores in fresh and processed samples (Fig. 4b); however, panelists detected increased firmness in processed MP with added *κ*-C and XG, matching the result for textural properties in MPB samples (Figs. 1c,f).

Attributes perceived at the time of preparing the sample in the mouth for swallowing. EVOO concentration, cryoprotectant addition and processing also had a significant effect on cohesiveness, adhesiveness and fibrousness (1) (Table 3). When EVOO concentration was increased, cohesiveness and adhesiveness scores decreased significantly in the MPB samples (Figs. 4C,D). In the MPA samples there were no significant differences between the adhesiveness scores of fresh and processed samples (Fig. 4E), whereas panelists scored the processed MPB samples higher for adhesiveness than their fresh counterparts. Scores for fibrousness (1) also decreased with increasing EVOO concentration, with cryoprotectant addition and with processing (Figs. 4F,G). Again, addition of cryprotectants reduced differences in fibrousness (1) between fresh and processed samples. This is probably related to the fact that the hydrocolloids can make systems in the rubbery state more viscous, reducing molecular mobility and preventing retrogradation (Ferrero *et al* .1994).

TABLE 3. EFFECTS OF EVOO CONCENTRATION, CRYOPROTECTANT ADDITION AND FREEZING/THAWING ON SENSORY ATTRIBUTES PERCEIVED BEFORE AND AT THE TIME OF PUTTING THE SAMPLE IN THE MOUTH, AND AT THE TIME OF PREPARING THE SAMPLE FOR SWALLOWING OF MP

Sensory attributes	Perceived before putting the sample in the mouth		Perceived at the time of putting the sample in the mouth					Perceived at the time of preparing the sample for swallowing		
Source	Granularity	Moisture(1)	Stickiness	Denseness	Homogeneity	Moisture(2)	Firmness	Cohesiveness	Adhesiveness	Fibrousness(1)
Main effects:										
A:EVOO concentration	<0.001	0.022	0.487	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
B:Cryoprotectant addition	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
C:Processing	<0.001	<0.001	0.542	<0.001	<0.001	<0.001	0.002	0.002	<0.001	<0.001
Interactions										
AB	<0.001	0.002	0.002	0.236	<0.001	<0.001	0.044	<0.001	<0.001	<0.001
AC	<0.001	0.003	<0.001	<0.001	<0.001	0.082	<0.001	0.292	0.818	<0.001
BC	0.015	0.001	0.611	<0.001	0.970	0.003	<0.001	0.083	<0.001	<0.001
ABC	<0.001	<0.001	<0.001	0.143	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

EVOO, extra virgin olive oil; LSD, least significant difference; MP, mashed potato.

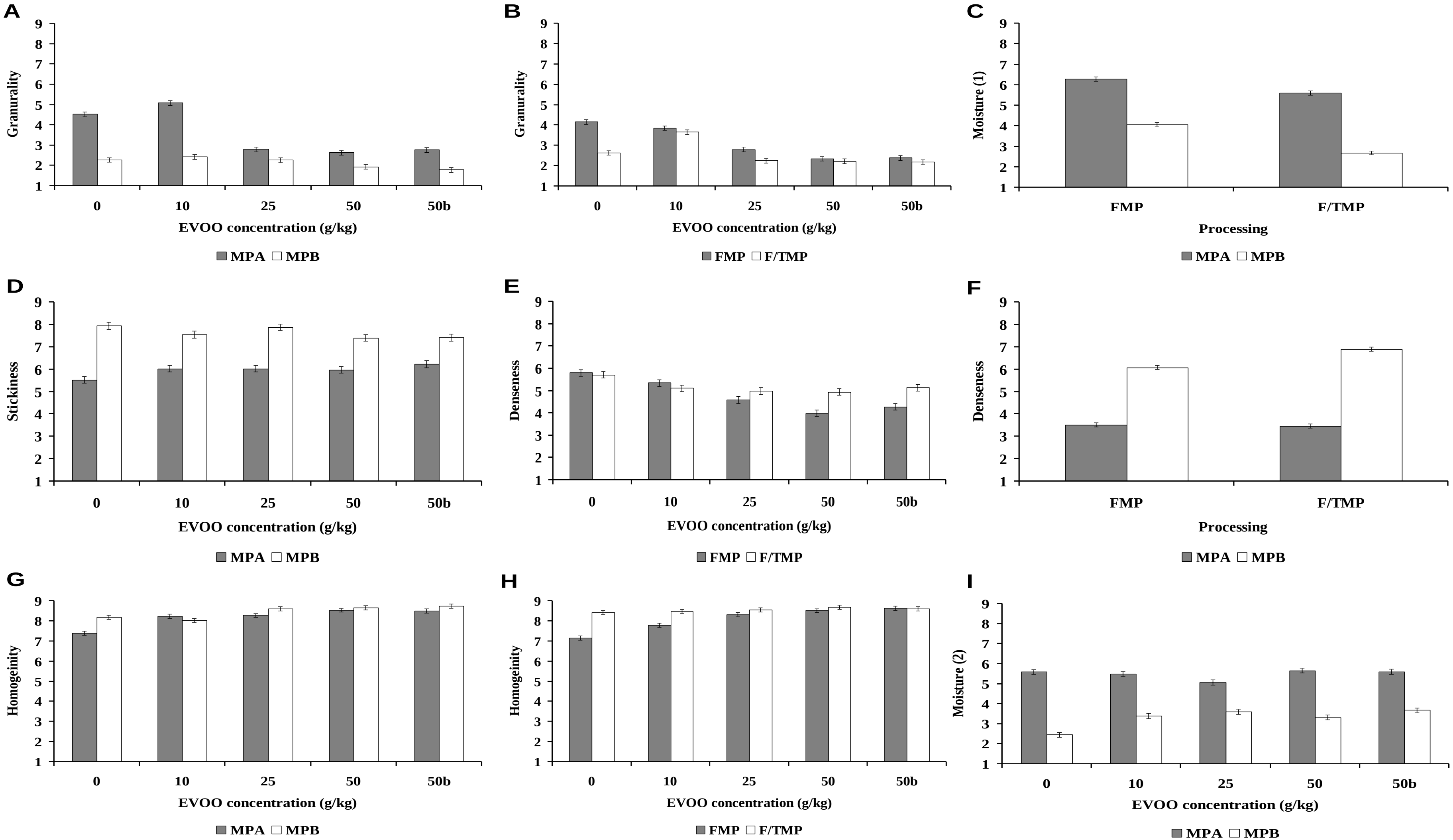

FIG. 3. TEXTURE PROFILE ANALYSIS SENSORY ATTRIBUTES OF MASHED POTATOES WITH ADDED EXTRA VIRGIN OLIVE OIL (EVOO). (A, B) Granularity; (C) Moisture (1); (D) Stickiness; (E, F) Denseness; (G, H) Homogeneity; (I) Moisture (2); MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively.

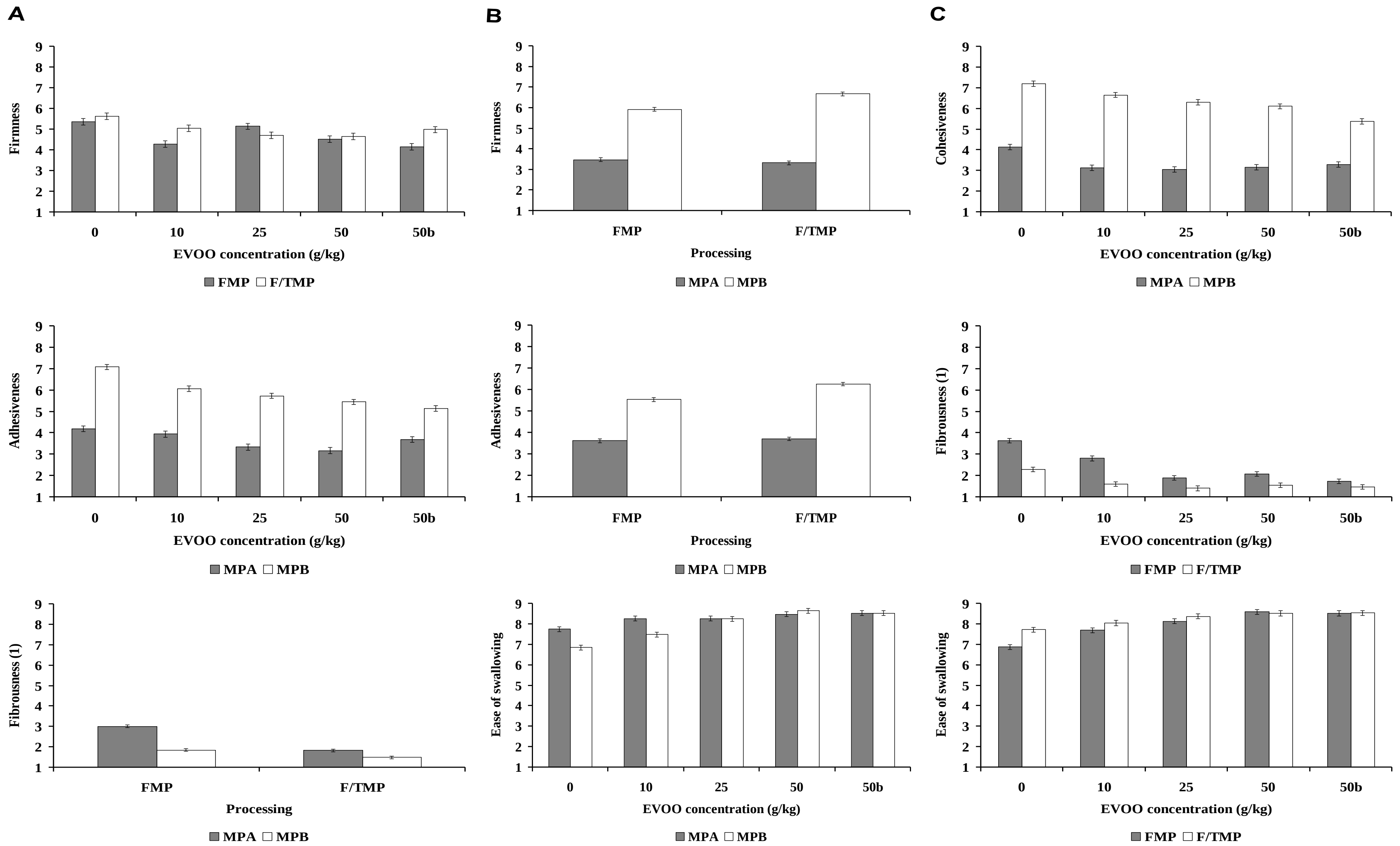

FIG. 4. TEXTURE PROFILE ANALYSIS SENSORY ATTRIBUTES OF MASHED POTATOES WITH ADDED EXTRA VIRGIN OLIVE OIL (EVOO). (A, B) Firmness; (C) Cohesiveness; (D, E) Adhesiveness; (F, G) Fibrousness (1); (H, I) Ease of swallowing; MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively.

Attributes perceived during final and residual phases of mastication. The three factors studied had a significant effect on ease of swallowing and fibrousness (2) (Table 4), whereas only EVOO concentration had a significant effect on palate coating. In samples both without and with added cryoprotectants (Fig. 4H) and in both FMP and F/TMP samples (Fig. 4I), ease of swallowing scores increased with increasing oil content. However, only when EVOO was added at concentrations of 0 and 10 g/kg, the scores for this attribute were higher in the samples without cryoprotectants and in the processed samples. Panelists also scored the samples with added EVOO significantly higher for palate coating than the ones made without EVOO (Figs. 5A,B). Scores for palate coating were higher in the MPA samples with 25 and 50 g/kg added EVOO than in their MPB counterparts (Fig. 5A), and the EVOO content had a much smaller effect in the F/TMP samples than in the fresh counterparts (Fig. 5B). Palate coating scores for MPA samples decreased after processing, whereas scores for MPB samples increased with respect to the fresh products (Fig. 5C). Also, in the MPA samples, the addition of EVOO at all concentrations significantly reduced sample fibrousness (2) (Fig. 5D).

TABLE 4. EFFECTS OF EVOO CONCENTRATION, CRYOPROTECTANT ADDITION AND FREEZING/THAWING ON SENSORY ATTRIBUTES PERCEIVED DURING THE FINAL AND RESIDUAL PHASES OF MASTICATION AND OVERALL ACCEPTABILITY OF MP

Sensory attributes	Perceived during the final and residual phases of mastication			Overall acceptability
Source	Ease of swallowing	Palate coating	Fibrousness (2)	
Main effects:				
A:EVOO concentration	<0.001	<0.001	<0.001	<0.001
B:Cryoprotectant addition	<0.001	0.520	<0.001	<0.001
C:Processing	<0.001	0.601	<0.001	<0.001
Interactions				
AB	<0.001	<0.001	<0.001	<0.001
AC	0.003	<0.001	<0.001	<0.001
BC	0.126	<0.001	<0.001	0.055
ABC	0.211	<0.001	<0.001	0.015

EVOO, extra virgin olive oil; LSD, least significant difference; MP, mashed potato.

A complete dependence study was performed on the instrumental textural properties versus sensory attribute scores. Low correlations between instrumental and sensory ratings were found. Previous publications by other researchers generally agree on good to excellent correlations for hardness (based on calculated "*r*" values (Szczesniak 2002). Correlations for other parameters are usually less good and product-dependent. In this study, relatively good correlations with sensory denseness and adhesiveness scores were found only in the case of viscosity index (R^2 = 0.81 and 0.76, respectively). Differences in consistency observed among samples were explained by viscosity index, but not the variation in granularity or fibrousness, determining the sample creaminess.

Overall acceptability. EVOO concentration, cryoprotectant addition and processing had a significant effect on the OA of the samples (Table 4). Scores for OA increased significantly with increasing EVOO content in both MPA and MPB samples (Fig. 5E), and likewise in both FMP and F/TMP samples (Fig. 5F). Similarly, a positive relationship between oil content and sensory acceptability has been observed in a set of Polish commercial mayonnaises (Juszack *et al*. 2003) and in salami (Severini *et al*. 2003). In this study, the main differences between samples without and with added EVOO were ascribed to either an aromatic or a creamy note detected in the oil-added MP. Samples with higher percentages of EVOO produced less sensations of dryness and roughness, more sensations of flavour, creamy and fatty mouth-and after-feel than the samples without added oil. Fat is a well-known enhancer of creaminess sensations (De wijk *et al*. 2003). The latter authors suggested that the possible mechanism by which fat affects the sensory attributes include lubrication and flavour release. The effects of fat on odour and flavour attributes may be related to the flavour-releasing properties of fat.

Panelists scored the MPB and F/TMP samples higher for OA (Figs. 5E,F). This is probably related to the presence of XG in the systems. It was found that samples containing blends of κ-C and XG (Alvarez *et al*. 2009; Fernández *et al*. 2009), were preferred organoleptically due to the creamy mouthfeel they produced. The effects of XG on mouth texture may be related to its WHC, as perceived by the panelists. Besides, in the processed MPB samples, there were no significant differences between the OA scores given to the MP at any concentration of added EVOO (which were the highest). This has important consequences for the formulation of EVOO-based MP. Results indicate that in the presence of κ-C and XG, if the EVOO content is reduced to below 25 g/kg, the OA score for the product does not decrease, and hence its consumer acceptability is not adversely affected.

Microstructure Examination

To achieve a better understanding of the sensory and rheological results and the effect of adding cryoprotectants and of freezing/thawing, the microstructure of the MP samples was studied by SEM (Figs. 6, 7). Fig. 6A shows a microphotograph of the fresh control without either added cryoprotectants or oil. Cooked cells are still distinguishable and firmly bound together by a continuous network of amylose. However, in the fresh control without added EVOO but with added cryoprotectants (Fig. 6B), less complete cells are visible, appearing separated from one another and embedded in a continuous network of amylose and κ-C in which starch granules and XG aggregates are entrapped. Probably, the presence of cryoprotectants occluding a great amount of water probably facilitated loss of the original cell shape.

Microphotographs of the corresponding processed counterparts (Figs. 6C,D) show that freezing and thawing of MPA and MPB samples resulted in completely dissolved cells. Part of the intracellular water was drawn out osmotically because of freezing-induced concentration of the cell mass. Cell tearing is probably caused by the formation of ice crystals. Fresh MPA sample contain more complete cells (Fig. 6A), which could give them greater mechanical strength; this would justify that the values of the textural properties were higher in fresh MPA samples than in their processed counterparts. In turn, the processed MPA sample without added EVOO (Fig. 6C) developed a spongy appearance due to amylose and amylopectin retrogradation occurring during freezing and frozen storage (Ferrero *et al*. 1994).

The microphotograph of processed MPB sample without added EVOO (Fig. 6D) shows the presence of fibres or strands. According to Giannouli and Morris (2003), during freezing, XG chains are forced to align and associate by conversion of water to ice crystals. The forced associations survive upon thawing to give a cryogel network. It is likely that such strands are related to this XG conformational transition, since they were observed in most of the F/TMP containing cryoprotectants. Formation of strands can be explained by a progressive increase in local concentration of the polymer as liquid water is converted into ice crystals, promoting intermolecular associations.

Figure 7 shows microphotographs of the counterparts of the samples shown in the Fig. 6, but with 50 g/kg added EVOO. When EVOO was added, a dispersed thin phase or layer of oil formed, enveloping all the microstructures constituting the MP. Figure 7A shows some oil droplets in MPA sample, probably formed by aggregation through steric and/or electrostatic forces (Paraskevopoulou *et al*. 2005), whereas Fig. 7B shows no oil droplets in presence of κ-C and XG. In MPA samples, freezing also had a negative influence of the formation of oil droplet clusters (Fig. 7C);

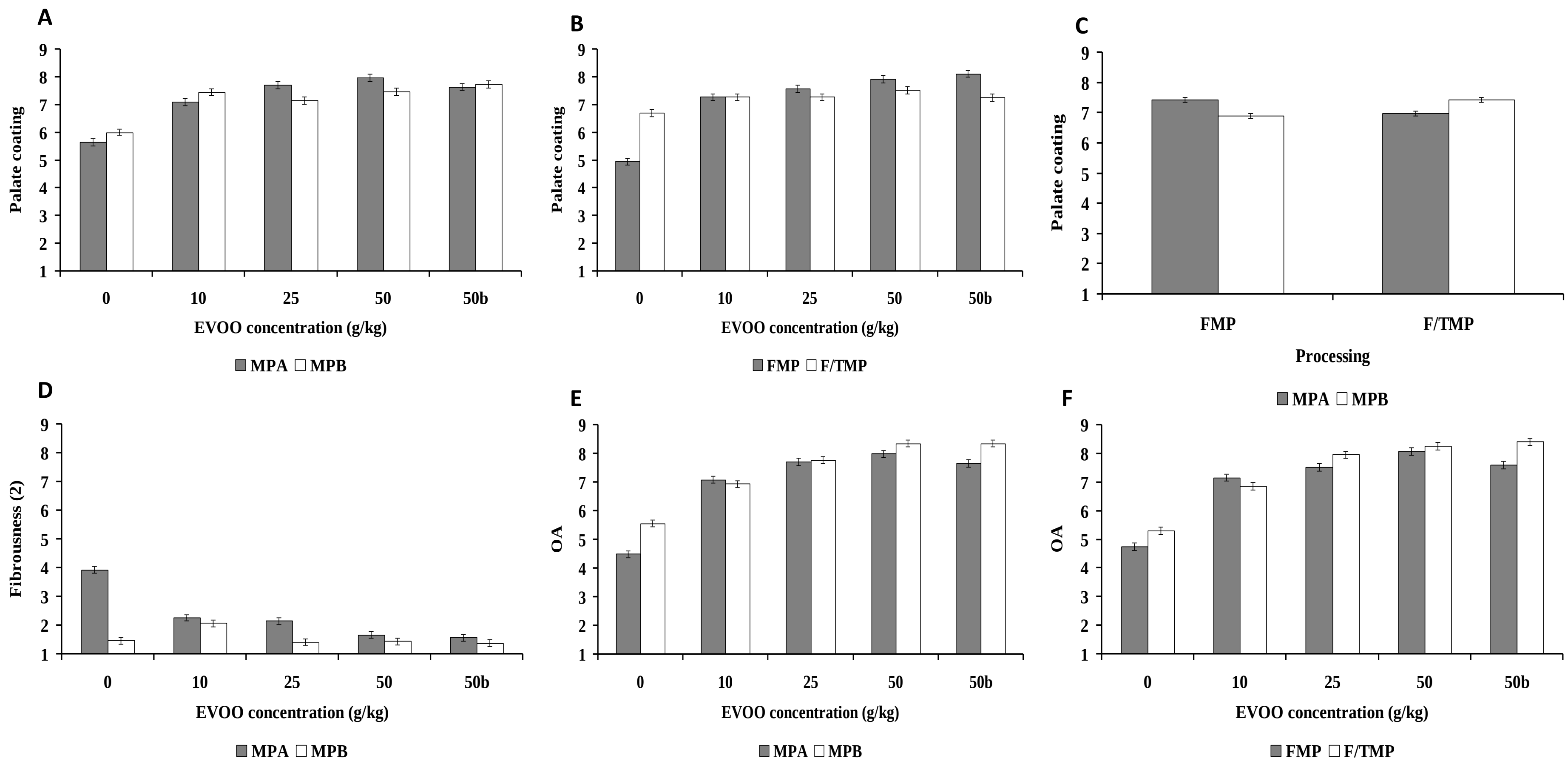

FIG. 5. TEXTURE PROFILE ANALYSIS SENSORY ATTRIBUTES AND OVERRALL ACCEPTABILITY OF MASHED POTATOES WITH ADDED EXTRA VIRGIN OLIVE OIL (EVOO) **(A-C) Palate coating; (D) Fibrousness; (E, F) Overall acceptability (OA); MPA, MPB: mashed potatoes without and with added cryoprotectants, respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes, respectively.**

it is likely that the structural damage caused by freezing enabled the oil droplets to come close enough together to aggregate. Microphotograph of the processed sample with 50 g/kg added EVOO (Fig. 7D) shows that white gel structures are also discernible in the presence of cryoprotectants.

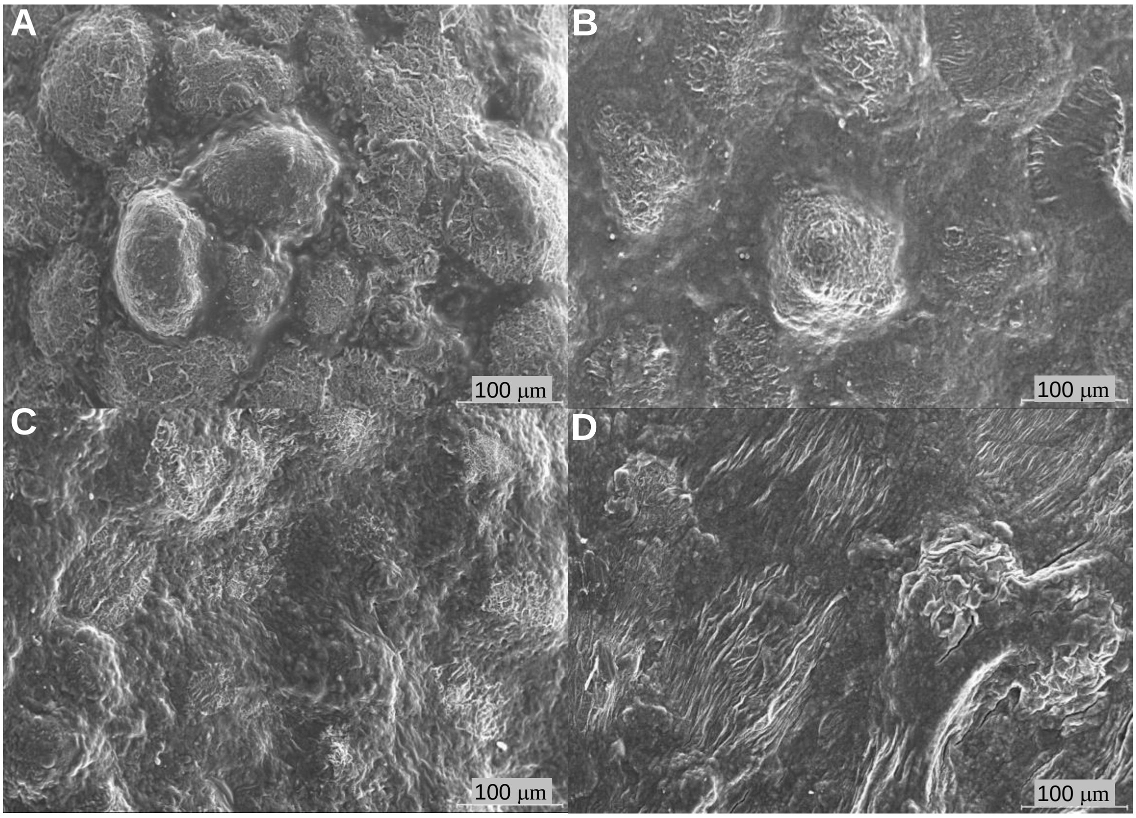

FIG. 6. MICROPHOTOGRAPHS OF MASHED POTATOES
(A) Fresh sample without added cryoprotectants; (B) Fresh sample with added cryoprotectants; (C) Processed sample without added cryoprotectants; (D) Processed sample with added cryoprotectants; Magnification was 200 (bar = 100 μm).

Addition of XG to salad dressings induces depletion flocculation of the droplets and formation of a three-dimensional weak gel network structure that retards the process of droplet creaming (Parker *et al*. 1995). Adding a hydrocolloid causes protein-coated droplets to aggregate and be excluded from the region of continuous phase between them. Therefore, in the MP with added *κ*-C and XG and oil, the XG may have been adsorbed onto the surface of the droplets, enhancing stability against flocculation and coalescence and forming the white film observed in both microphotographs (Figs. 7B,D). On the other hand, there are no noticeable differences between FMP and F/TMP samples with added κ-C and XG and oil, confirming that the addition of κ-C and XG significantly reduced quality differences between FMP and their F/TMP counterparts.

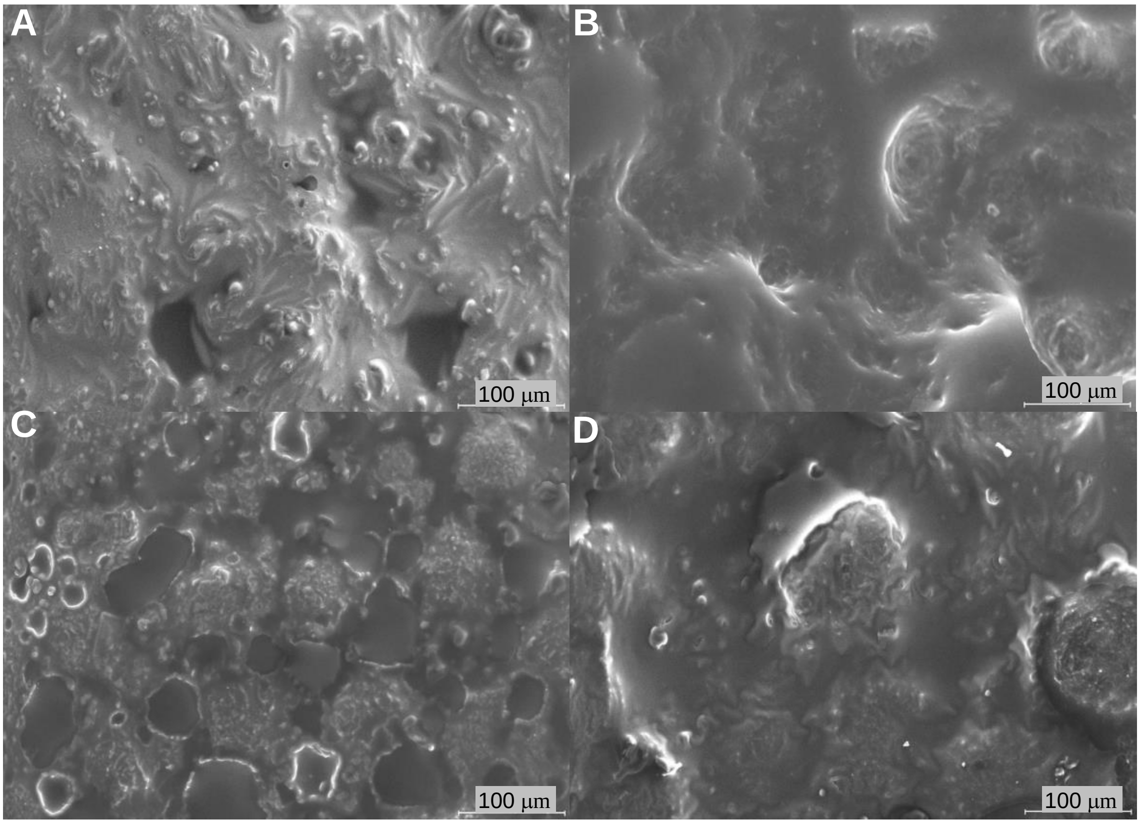

FIG. 7. MICROPHOTOGRAPHS OF MASHED POTATOES WITH ADDED EXTRA VIRGIN OLIVE OIL (EVOO)
(A) Fresh sample without added cryoprotectants and with 50 g/kg added EVOO; (B) Fresh sample with added cryoprotectants and with 50 g/kg added EVOO; (C) Processed sample without added cryoprotectants and with 50 g/kg added EVOO; (D) Processed sample with added cryoprotectants and with 50 g/kg added EVOO; Magnification was 200 (bar = 100 µm).

CONCLUSION

The addition of either EVOO or cryoprotectants and processing significantly affected the physical, structural and sensory characteristics of MP, although the effect of EVOO concentration depended on the presence of cryoprotectants and on freezing/thawing. Increased EVOO concentration resulted in less structured systems and enhancement of color due to an increase in overall light scattering and pigment content. Addition of κ-C and XG improved thickness, possibly through the exclusion effect of swollen starch granules promoting gelation of the κ-C. Addition of EVOO in increasing concentrations enhanced the sensory quality of MP in terms of reduced granularity, denseness, cohesiveness, adhesiveness and fibrousness, and increased homogeneity, ease of swallowing and palate coating. Instrumental texture measurements were able to distinguish the variations in mechanical textural attributes scored by the panellists. Conversely, geometrical textural attributes (granularity, homogeneity and fibrousness) have to be support by structural traits. Creaminess was the most crucial factor for OA of the products and could be explained by the presence of EVOO aggregates observed by microstructure analysis. Samples with 50 g/kg added EVOO were judged the best of all. There is a possibility of using EVOO in combination with MP to provide a highly nutritious product with improved physicochemical, functional and sensory characteristics.

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SENSORY AND TEXTURE PROPERTIES OF MASHED POTATO INCORPORATED WITH INULIN AND OLIVE OIL BLENDS.

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ABSTRACT

The effect of adding different ratios of inulin (INL) and extra virgin olive oil (EVOO) blends, formulated without (MPA) and with cryoprotectants (MPB), on texture properties of fresh (FMP) and frozen/thawed mashed potatoes (F/TMP) was studied. INL and EVOO behaved like soft fillers, but INL was associated with increased fibrousness and EVOO with increased creaminess. In the total dataset and FMP, F/TMP and MPA subgroups, component 1 was a contrast between mechanical and surface textural attributes, whereas in MPB samples component 1 was determined by geometrical attributes. Addition of INL at 30 g/kg and EVOO at 45 g/kg is recommended.

KEYWORDS

Mashed potatoes, Inulin, Extra virgin olive oil, Principal component analysis, Sensory properties, Back extrusion

INTRODUCTION

Recent changes in our lifestyles have led to an increasing demand for convenience foods, and our growing awareness of the relationship between food and health has increased the demand for higher-fiber, lower-fat products.[1] However, the addition of functional and nutritional food ingredients such as inulin (INL) and/or extra virgin olive oil (EVOO), will produce perceptible differences in the sensory properties of mashed potatoes (MP). In most cases, INL has been added to different foods, in amounts ranging from 3 to 6 g per portion, to increase soluble fiber ingestion, or to assure bifidus production by adding 3–8 g per portion.[2] INL is also currently used in food formulations as a techno-functional agent for fat replacement, bulking, water retention, etc.[3] A fat-like texture can be achieved by increasing the INL concentration and average degree of polymerization above a critical value.[4] In particular, long-chain INL can act as a fat mimetic due to its capacity to form microcrystals, which interact with one another to form small aggregates that occlude a large amount of water; thus creating a fine, creamy texture that gives a mouthfeel similar to that of fat.[5]

Olive oil is an important dietary component of Mediterranean countries, and EVOO has nutritional and sensory characteristics that make it unique. On November 2004, the US Federal Drug Administration (FDA) permitted the following claim on olive oil labels concerning “the benefits on the risk of coronary heart disease of eating about 2 tablespoons (23 g) of olive oil daily, because of the monounsaturated fat (MUFA) in olive oil”.[6] It is expected that consumers can attain this daily intake from different olive oil-containing foods.

Technologically, the industry increasingly needs to be able to understand and control texture and is therefore willing to help promote more innovation and new product development. Today, texture is seen as a positive quality attribute denoting product freshness, excellent food preparation and eating enjoyment.[7] Textural evaluation is consequently an important step in assessing the functionality of food products. Sensory evaluation of foods and beverages is also important and is usually carried out using conventional techniques such as descriptive analysis.[8] A sensory panel test was used to evaluate instrumental parameters and the sensory texture in cooked potatoes.[9] A sensory texture profile analysis uses trained assessors to describe and give quantitative texture measures of a given food. This is applied using standard rating scales, which provide a quantitative evaluation of the mechanical and other texture parameters by measuring qualitative and quantitative textural differences of similar samples. A sensory descriptive texture profile including thirteen sensory attributes (geometrical, mechanical, surface and other residual characteristics) was developed for MP in which the panel produced reliable results for most of the attributes with respect to discriminative ability and reproducibility.[10]

Principal component analysis (PCA) is among the multivariate techniques that can be applied to extract relevant information from descriptive sensory trials. In the case of highly correlated data, typical of sets of food-quality measurements, PCA will typically lead to a small number of fused feature variables (the principal components), which are always orthogonal and often have a ready physical interpretation.[11] This reduction should aim at identifying those descriptors that are sufficient to describe the product, while at the same time avoiding characteristics that are difficult to quantify.

As an MP sample behaves like a high-volume-fraction dispersion, the addition of INL (extra dry matter) would be expected to result in a firmer product. However, there is little information on the sensory characteristics of INL and how it may be affected by interactions with other ingredients like starch or different kinds of hydrocolloids; nor is there information available on the effects of EVOO incorporation on the sensory characteristics of MP products. EVOO is a liquid material, and therefore a system to which it is added would be expected to be softer whatever the concentration used. Therefore, MP formulation may be optimized not only to improve nutritional value but at the same time to gain more insights into the sensory properties of such systems.

The purpose of the present research was therefore: (1) to evaluate the effect of adding different ratios of INL/EVOO blends on the sensory properties and instrumental texture measurements of FMP and F/TMP formulated without and with added cryoprotectants (kappa-carrageenan and xanthan gum); (2) to reduce and explain the perceived texture by means of linear combinations of the sensory attributes, using PCA.

The reliability of the sensory properties and the panel consonance are also discussed in some detail.

MATERIALS AND METHODS

Material

The potatoes used were fresh tubers (cv Kennebec) from Aguilar de Campoo (Burgos, Spain). INL with the trade name Orafti®HP (BENEO-Orafti, Tienen, Belgium) was a “long-chain” INL with an average DP (total number of fructose or glucose units) ≥ 23 and purity of 99.5% (producer’s data). EVOO (Carbonell, Sevilla, Spain) was chosen for addition to the MP. Kappa-carrageenan (κ-C) (GENULACTA carrageenan type LP-60) and xanthan gum (XG) (Keltrol F [E]) were donated by Premium Ingredients, S.L. (Girona, Spain). Five different I:EVOO blend ratios were added to the samples (15 g/kg (I)/45 g/kg (EVOO), 15:45; 30 g/kg (I)/30 g/kg (EVOO), 30:30; 45 g/kg (I)/15 g/kg (EVOO), 45:15; 30 g/kg (I)/45 g/kg (EVOO), 30:45; 45 g/kg (I)/30 g/kg (EVOO), 45:30). Additional samples without added ingredients (0:0 control), with 60 g/kg added I alone (60:0) and with 60 g/kg added EVOO alone (0:60) were also prepared for each type of MP and processing condition.

Preparation of MP Samples

Tubers were manually washed, peeled and diced. MP were prepared in ~2,000 g batches from: 1,185 g of potatoes, 450 mL of semi-skimmed in-bottle sterilized milk (fat content, 15.5 g/kg), 300 mL of water, 15 g of salt (NaCl) and the corresponding EVOO concentration (0-60 g/kg), depending on the I:EVOO ratio, using a TM 31 food processor (Vorwerk España, M.S.L., S.C., Madrid, Spain). In turn, the corresponding INL concentration (0-60 g/kg) was previously dissolved in 750 mL of water and milk at 70°C for 15 min and agitated with a magnetic stirrer at 600 rpm. MPs were prepared without and with added κ-C and XG (MPA and MPB samples, respectively). In the latter case, hydrocolloids (each at 1.5 g/kg) were added to the rest of the ingredients in dry powder form. All the ingredients were cooked for 35 min at 90°C (blade speed: 0.10 × g).[10, 12] The mash was ground for 40 s (blade speed: 80 × g) and for 20 s (blade speed: 1,000 × g) and then immediately homogenized through a stainless steel sieve (diameter: 1.5 mm). Half of each fresh blend (FMP samples) was analyzed at once and the other half was frozen and subsequently thawed (F/TMP samples). Two repetitions of each composition were prepared in different weeks for randomization.

Freezing, Thawing and Heating Procedures

MP samples were placed on flat-freezing and microwave thawing trays, and then frozen by forced convection with liquid nitrogen vapor in an Instron programmable chamber (model 3119-05, −70/+250°C) at −60°C until their thermal centers reached −24°C.[13] After freezing, the samples were packed in polyethylene plastic bags, sealed under light vacuum (–0.05 MPa) on a Multivac packing machine (Sepp Haggenmüller KG, Wolfertschwenden, Germany), and placed in a domestic freezer for storage at −24°C. Packed frozen samples were thawed in a Samsung M1712N microwave oven (Samsung Electronics S.A., Madrid, Spain) by heating for 20 min at an output power rating of 600 W. After thawing, the temperature reached at the product thermal center was measured in all cases (+75 ± 5°C). The temperature was then reduced to 55°C by placing the samples in a Hetofrig CB60VS water bath (Heto Lab Equipment A/S, Birker∅d, Denmark) as this is the preferred temperature for MP consumption.[10]

Sensory Analysis

MP samples were subjected to texture profile analysis (TPA), modified to evaluate vegetable purees according to UNE 87025 (1996)[14] and other relevant International Standards,[15] and then used to select and define the sensory attributes included in the profile. A panel of 4 assessors, previously trained according to the ISO guidelines[16] and with 8 years of specific experience assessing MP, evaluated the textural attributes of the samples. Descriptive panels usually have 8 to 12 assessors though they may have more, or as few as 4.[17] An important point to note here is that as it is the assessors themselves who are the measuring instruments in sensory analysis, it is necessary to confirm their efficacy by evaluating the consistency of their replies and their ability to distinguish differences.[18] In fact attempts have been made to train and incorporate new members to the panel. In these cases, models of analysis of variance ANOVA have been performed with interactions for each attribute including assessor and sample as factors. The results showed significant effects of assessor × sample interaction, illustrating disagreement among the new assessors and the 4 earlier members in scoring the samples for a lot of attributes. Certainly, specific instructions regarding panel size are not appropriate because of the many factors that have to be considered.[17]

Profile attributes were classified into four groups (Table 1). Attributes are listed in order of perception according to ISO guidelines.[17] Note that for moisture and fibrousness, numbers in brackets (1) and (2) refer to the order of their perception in the mastication process. Samples were evaluated in duplicate in morning sessions (1:00 p.m.), every day for 64 days, and assessors were given four samples (about 20 g each) for scoring the attributes of each group in the texture profile. All the samples were served at 55°C in white plastic vessels, and the sample temperature was reached and kept constant by placing the product in the Hetofrig CB60VS water bath prior to testing. For each sample, panelists evaluated the perceived intensity of the 13 attributes on 8 cm descriptive linear scales labeled at each anchor: (left anchor: 1 = ‘‘not detectable”; right anchor: 9 = ‘‘extremely intense’’). To reduce fatigue a rest period of 5 min was taken after scoring each sample.

Instrumental Texture Measurements

A back extrusion (BE) test was performed using a TA.HDPlus Texture Analyzer (Stable Micro Systems Ltd, Godalming, UK) equipped with a 300 N load cell.[19] During tests, MP samples were kept at 55°C by means of a temperature controlled Peltier cabinet (XT/PC) coupled to a heat exchanger and a proportional-integral-derivative (PID) controller. For BE tests, a rig (model A/BE, Stable Micro Systems) was used consisting of a flat 45 mm diameter Perspex disc plunger that moved within a 50 mm inner diameter Perspex cylinder sample holder containing 50 ± 1 g of MP sample. The product was extruded to a distance of 20 mm at a 2 mm/s compression rate. Recorded force time curves provided the maximum positive force of extrusion (BE firmness (N)) and the negative area of extrusion (BE viscosity index (N s)).[20] Texture measurements were performed in quadruplicate and results averaged.

Expressible Water

Expressible water (*Ew*) was measured by centrifugal force according to Eliasson and Kim. [21] Centrifuge tubes containing approximately 10 g of MP were centrifuged at 15,000 × g for 30 min in a Sorvall®, RC-5B apparatus (Global Medical Instrumentation, Inc, Clearwater, MN). E_w was expressed as the percentage of liquid separated per total

TABLE 1. LIST OF DESCRIPTIVE TERMS AND DEFINITIONS USED IN THE SENSORY ANALYSIS OF MASHED POTATOES BY TRAINED PANEL.

Descriptors	Definitions
Perceived before placing the sample in the mouth	
Granularity, Gra	Geometrical textural attribute reflecting the size and shape of the particles (the terms “creamy, floury, lumpy, gritty and grainy” are used to convey an ascending scale of particle size perception).
Moisture (1), Moi (1)	Surface textural attribute reflecting the absorption of water by the mashed potato (the commonest terms are surface attributes: dry, moist and wet).
Perceived at the time of placing the sample in the mouth	
Stickiness, Sti	Mechanical textural attribute reflecting the effort required to separate the food from another surface (e.g., a spoon).
Denseness, Den	Geometrical textural attribute reflecting the degree of solidness or compactness of the sample.
Homogeneity, Hom	Geometrical textural attribute reflecting the degree to which the sample is free of particles or irregularities.
Moisture (2), Moi (2)	Surface textural attribute reflecting the water content of the mashed potato (the commonest terms are body attributes: dry, moist, juicy, succulent and watery).
Firmness, Fir	Mechanical textural attribute relating to the force required to achieve a given deformation, penetration, or breakage of the mashed potato (the intensity is perceived as the level of force required to compress a sample between tongue and palate).
Perceived upon preparing the sample in the mouth for swallowing	
Cohesiveness, Coh	Mechanical textural attribute reflecting the effort required to reduce the mashed potato to a state suitable for swallowing, taking into account the potato’s resistance to disintegration.
Adhesiveness, Adh	Mechanical textural attribute reflecting the effort required to separate the food from any surface inside the mouth (teeth, gums, palate); the intensity is perceived as the level of force required to separate the compressed sample from bucal surfaces (especially the palate) with the tongue.
Fibrousness (1), Fib (1)	Geometrical textural attribute reflecting the fiber content perceived during preparation of the sample in the mouth prior to swallowing.
Perceived during final and residual phases of the mastication process	
Ease of swallowing, Eas	Property reflecting the ease with which the mashed potato is transferred to the back of the palate and swallowed.
Palate coating, Pal	Property reflecting the sensation of mashed potato remaining on the palate after swallowing or ingestion.
Fibrousness (2), Fib (2)	Geometrical textural attribute reflecting the fiber content perceived during actual swallowing or ingestion of the mashed potato, and the sensations perceived in the residual phase.

weight of sample in the centrifuge tube. Measurements were performed in quadruplicate and the results averaged.

Statistical Analyses

A three-way analysis of variance (ANOVA) with interactions was applied to evaluate how the three factors studied—INL:EVOO ratio, presence or absence of hydrocolloids and performance or not of a freeze/thaw cycle—affected the sensory attributes and the instrumental texture measurements of the MP. A two-way ANOVA with interactions was applied to evaluate how the INL:EVOO ratio and freeze/thaw cycle affected the E_w of the products and it was found that the E_w was always zero for all the MPB samples. Minimum significant differences were calculated using Fisher's least significant difference tests (95% for comparison of sensory attributes and 99% for comparison of instrumental parameters).

The dataset (n = 256) and the FMP (n = 128), F/TMP (n = 128), MPA (n = 128) and MPB samples (n = 128) were analyzed by PCA to investigate the interdependence of the sensory attributes via identification of new, uncorrelated variables. Statistical analyses were performed with Statgraphics® software version 5.0 (STSC Inc., Rockville, MD, USA).

RESULTS AND DISCUSSION

Influence of Composition and the Freeze/Thaw Cycle on Sensory Attributes of MP Samples

Table 2 shows the effects of the three factors studied on the scores awarded to the sensory attributes of the MP samples. Graphs of the sensory attributes for different binary interactions are shown in Figs. 1 and 2. Binary interactions were considered since their importance (F values) is mostly much higher than the triple interactions. All the three main factors significantly ($P < 0.05$) affected the textural attribute scores with some exceptions such as homogeneity and ease of swallowing scores, which were unaffected by cryoprotectant addition and the freeze/thaw cycle respectively. The three binary interactions also had a significant effect on most sensory attribute scores, although only the INL:EVOO ratio, cryoprotectant addition (AB), the INL:EVOO ratio and the freeze/thaw cycle (AC) interactions significantly affected granularity and ease of swallowing scores.

Attributes Perceived before Putting the Sample in Mouth. Fig. 1a shows the variation in granularity based on the INL:EVOO ratio for both MPA and MPB samples. One can observe that, except for samples with an added 30:30 ratio, granularity scores were higher in the MPA samples. The presence of XG in the MPB systems reduced the grainy appearance by slowing or preventing starch retrogradation during the freeze/thaw cycle.[22-24] Brennan *et al*.[25] studied the pasting properties and freeze/thaw stability of natural waxy maize starches in the presence of XG using a Rapid Visco Analyzer (RVA) and turbidimetric analysis. Freeze/thaw stability was determined after four cycles over a 4 weeks period during which XG reduced starch retrogradation and increased freeze/thaw stability. Arocas *et al*.[26] reported that gums like XG affect the gelatinization and retrogradation of starch through strong associations with amylose, resulting in reduced amylose-amylose interactions. Visually, the texture of frozen/thawed MPA samples appeared to be spongy, stratified and flaky, as reflected by the significant increase in granularity scores. This undesirable appearance was not observed in the MPB samples.

In both MPA and MPB samples, panelists judged granularity to be higher in samples with an added 60:0 ratio than in the 0:0 control, even though in the MPB products granularity scores in the samples with added 15:45, 30:30, 45:15 and 45:30 ratios were also significantly higher than those for the 0:0 control, and increased with increasing INL content. Furthermore, panelists found that samples with added 60:0 and 45:15 ratios had a sandy texture associated with the presence of large INL crystals which were even visible to the naked eye. The initial INL concentration may affect both the crystallization and aggregation processes and consequently the rate of sedimentation.[27] At 45 and 60 g/kg, INL concentrations, the chains crystallize faster, which could explain the sedimentation detected in these samples. On adding long-chain INL some aggregates formed, embedded in a continuous network composed mainly of milk proteins with some immersed starch granules.[28] These aggregates were characterized by a rough outline, which could justify the significant increase in the perceived grainy appearance. On the contrary, at a fixed total concentration (60 g/kg), in both MPA and MPB samples, panelists judged granularity to be lowest in the samples with higher EVOO concentrations (0:60 and 15:45 ratios). Also, with a fixed INL content in both MPA and MPB samples, granularity scores decreased significantly with increasing EVOO content. These effects of EVOO on decreasing granularity are related to the lubricating and coating properties conferred by the oil as reported for vanilla custard desserts.[29]

Variation in moisture (1) based on the INL:EVOO ratios for both MPA and MPB samples are shown in the graph in Fig. 1b, and in all cases panelists detected increased aqueousness in the samples with added ingredients, whether alone or in associated blends. EVOO is a liquid material, and therefore, on adding EVOO, the systems would be expected to be moister whatever the concentration used. On the other hand, as MP samples behave like a high-volume-fraction dispersion, the addition of INL (extra dry matter) would be expected to result in a drier product. However, both ingredients appeared to produce a similar effect on this surface textural attribute. The INL long-chain structure resembles that of a network of fat crystals in oil, since this type of INL forms small microcrystal aggregates that occlude a considerable amount of water.[27] In fact, again in both MPA and MPB samples at a fixed EVOO concentration, moisture (1) scores increased linearly with INL content in all cases (15:45 vs 30:45 ratio and 30:30 vs 45:30 ratio), whereas at a fixed INL concentration, moisture (1) only increased linearly with EVOO concentrations in MPA (30:30 vs 30: 45 ratios) and MPB (45:15 vs 45:30) samples. Therefore, panelists detected that it was much easier to increase visual moisture (1) when INL was added to the systems. As suggested by Kim and Wang,[30] heating time probably induced INL hydrolysis which in turn led to an increase in the reducing sugar concentration and probably caused a decrease in average polymer chain lengths. According to the latter authors, temperatures above 80°C under neutral conditions caused some degree of hydrolysis of dissolved highly-polymerized INL molecules, and long INL chains were probably degraded into smaller ones which were unable to form a gel. Panelists also detected less aqueousness, and hence a greater ability to hold water molecules in MPB samples. XG is an anionic, hygroscopic material of exceptional pseudoplasticity,[31] and its texturizing effect can be achieved at low gum concentrations because of its unusual water-holding ability.

Attributes Perceived at the Time of Putting the Sample in the Mouth. The variation in stickiness scores determined by the INL:EVOO ratio in both FMP and F/TMP samples, shown in Fig. 1c, indicates that stickiness was significantly higher in the fresh samples than in those subjected to a freeze/thaw cycle when EVOO was added either alone (0:60 ratio) or blended with INL at increasing concentrations. Though EVOO behaves like a soft filler suspended in a rigid matrix, it still confers stickiness to the product, which may be related to the coating properties of the oil.[29] In the F/TMP samples, panelists judged stickiness to be lower in the systems with added INL:EVOO ratios than in the 0:0 control.

The panelists also detected higher denseness in both MPA and MPB samples without either added INL or EVOO (Fig. 1d). In all cases, denseness scores were significantly higher in the MPB than in the MPA samples; this result is attributed to the gelling properties of the κ-C as reported previously.[12] At a fixed total concentration, denseness scores were lower in the MPA samples with only added INL (ratio 60:0) than in those with only added EVOO (ratio 0:60). According to Carriere[32] the transition from dilute to semi-dilute solution behavior in polymers is designated as c^*, and the results seem to indicate that INL did not reach the c^* concentration even at the highest concentration used in this study (60 g/kg). In the MPA samples, panelists judged denseness to be highest in the samples with an added 30:30 ratio, indicating the positive synergistic effect of the two ingredients. Homogeneity scores were higher in the F/TMP samples than in their FMP counterparts (Fig. 1e), and the I:EVOO ratio affected homogeneity much less in the F/TMP samples than in their fresh counterparts. All this suggests that the effect of INL addition on the presence of irregularities in the MP samples is negative at higher fructan concentrations, although this effect is counteracted by a freeze/thaw cycle.

In comparison with 0:0 control, panelists detected greater moisture (2) in both FMP and F/TMP systems with added INL/EVOO blends (Fig. 1f), as in the case of moisture (1). The panelists also detected increased aqueousness in the FMP samples with added blend ratios of 60:0 and 45:15. Sensory firmness assessment confirmed that both INL and EVOO behave like soft fillers, with olive oil suspended and INL entrapped in a continuous phase (amylose/amylopectin matrix) due to the disruption and complete solubilization of the potato starch granules. At a fixed total concentration (Fig. 2a), there were non-significant differences between the firmness scores of the MPB samples with addition ratios of 60:0, 0:60, 15:45 and 30:30 as well as between the firmness scores of the MPA samples with addition ratios of 60:0, 15:45 and 30:30. This suggests that at the same concentration both ingredients produced a similar effect on the thickness of the samples. Nevertheless, at fixed EVOO and INL concentrations the decrease in firmness when both INL and EVOO concentrations were increased was more significant in the case of the MPB samples (ratios of 15:45 vs 30:45 and 30:30 vs 45:30) and (ratios of 30:30 vs 30:45 and 45:15 vs 45:30) respectively.

Attributes Perceived at the Time of Preparing the Sample in the Mouth for Swallowing. The variations in cohesiveness and adhesiveness scores for INL:EVOO ratios of both MPA and MPB samples as well as FMP and F/TMP samples are shown in Figs. 2b and 2c, respectively. At a fixed total concentration, cohesiveness scores were higher in the MPA samples with addition ratios of 15:45, 30:30 and 45:15, and lower with ratios of 0:60 and 60:0 ratios. These results suggest that in the MPA samples synergism between EVOO and INL also positively affected cohesiveness when they were added in associated blends, as compared to the scores awarded when they were added singly (ratios of 60:0 and 0:60). On the other hand, cohesiveness scores were lower in the MPB samples with addition ratios of 15:45 and 30:30 than in those with ratios of 0:60 and 60:0, supporting the hypothesis that the presence of cryoprotectants masked the effect produced by INL:EVOO ratio variations on the cohesiveness of these samples. Moreover, at fixed EVOO and INL concentrations cohesiveness decreased linearly in both MPA and MPB samples with increasing INL and EVOO concentrations. In the FMP samples, at a fixed total concentration, adhesiveness scores were higher in the samples with higher EVOO concentrations (0:60 and 15:45 ratios) (Fig. 2c), although there were non-significant differences among the adhesiveness scores of the FMP samples with addition ratios of 60:0, 30:30 and 45:15. This again indicates that both ingredients produced a very similar effect on adhesiveness. However, in the F/TMP samples, at a fixed total concentration, panelists judged adhesiveness to be highest in the samples with lower EVOO concentrations (ratios of 60:0 and 45:15).

Fibrousness (1) scores increased with respect to 0:0 control when INL was added alone and when EVOO was added at a concentration of 15 g kg-1 (45:15 ratio), but decreased with increasing EVOO content, with cryoprotectant addition and with processing (Table 2). These variations in the fibrousness (1) score for the INL:EVOO ratio in both FMP and F/TMP samples (Fig. 2d) shows that except for the samples with an addition ratio of 30:30, fibrousness (1) was significantly lower in the F/TMP samples than in the FMP ones. This result is probably related to the presence of XG in the MPB frozen/thawed systems, which reduced fibrousness (1). Hydrocolloids can make rubbery systems more viscous, reducing molecular mobility and preventing retrogradation.[22, 23] Furthermore, at a fixed total concentration there were no significant differences between the fibrousness scores of the F/TMP samples. On the other hand, fibrousness (1) scores were significantly higher in the FMP samples with higher INL contents (60:0 and 45:15 ratios). Kim *et al*.[4] found differences in INL particle sizes between low shearing, high shearing and thermally induced gels. The average particle size of INL crystals varied from 30 μm for low-shear-induced gel to approximately 2 μm for thermally induced gels. Changes in the particle distribution were also observed with the apparition of new particles (<10 μm) that were ascribed to INL crystal aggregates formed during the continuous phase of the system. According to this information, the increase in fibrousness (1) perceived for samples with higher I contents could be explained by the presence of large INL crystal aggregates.

TABLE 2. EFFECTS OF INL:EVOO RATIO, CRYOPROTECTANT ADDITION AND FREEZE/THAW CYCLE ON MEAN VALUES OF SENSORY ATTRIBUTE SCORES FOR THE MP SAMPLES. MEANS AND *F* VALUES.

Sensory attributes	Perceived before putting the sample in the mouth		Perceived at the time of putting the sample in the mouth					Perceived at the time of preparing the sample for swallowing			Perceived during the final and residual phases of mastication		
	Granularity	Moisture (1)	Stickiness	Denseness	Homogeneity	Moisture (2)	Firmness	Cohesiveness	Adhesiveness	Fibrousness (1)	Ease of swallowing	Palate coating	Fibrousness (2)
Main effects:													
A: INL:EVOO ratio													
0:0 control	2.77^{c}	2.72^{e}	$6.38^{a,b}$	6.61^{a}	8.54^{a}	2.79^{d}	6.53^{a}	6.45^{a}	6.16^{a}	2.29^{c}	6.14^{f}	6.14^{d}	$2.32^{b,c}$
60:0	4.32^{a}	5.60^{a}	5.80^{c}	4.71^{f}	7.87^{c}	4.87^{a}	4.56^{e}	4.87^{c}	4.64^{c}	2.72^{a}	6.91^{e}	5.97^{d}	2.56^{a}
0:60	1.79^{f}	4.71^{c}	6.51^{a}	$5.17^{c,d}$	8.54^{a}	4.18^{c}	4.93^{c}	5.03^{c}	$4.72^{b,c}$	1.96^{d}	8.07^{c}	7.52^{a}	$1.49^{e,f}$
15:45	1.74^{f}	4.02^{d}	6.22^{b}	5.23^{c}	8.36^{b}	4.06^{c}	5.17^{b}	4.99^{c}	$4.72^{b,c}$	1.96^{d}	8.00^{c}	7.43^{a}	1.78^{d}
30:30	2.16^{e}	4.15^{d}	5.79^{c}	5.66^{b}	8.55^{a}	4.24^{c}	5.20^{b}	5.41^{b}	4.31^{d}	1.56^{e}	7.59^{d}	7.41^{a}	1.38^{f}
45:15	3.13^{b}	4.81^{c}	5.78^{c}	$4.97^{d,e}$	8.32^{b}	4.09^{c}	$4.76^{c,d}$	5.32^{b}	4.91^{b}	2.54^{b}	6.91^{e}	6.46^{c}	$2.44^{a,b}$
30:45	1.70^{f}	5.36^{b}	5.64^{c}	4.75^{f}	8.61^{a}	4.56^{b}	$4.57^{d,e}$	4.26^{d}	4.56^{c}	1.62^{e}	$8.29^{a,b}$	6.87^{b}	1.54^{e}
45:30	2.41^{d}	5.17^{b}	5.61^{c}	$4.83^{e,f}$	8.24^{b}	4.14^{c}	4.74^{c-e}	4.43^{d}	4.56^{c}	2.32^{c}	$8.12^{b,c}$	6.96^{b}	2.28^{c}
F values	235.62	135.42	20.17	73.56	18.63	11.60	81.55	70.73	57.51	87.06	121.14	61.41	88.12
B:Cryoprotectant addition													
MPA: without κ-C and XG	2.88^{a}	5.99^{a}	4.67^{b}	3.88^{b}	8.40^{a}	5.01^{a}	3.70^{b}	3.94^{b}	3.30^{b}	2.30^{a}	8.01^{a}	6.54^{b}	2.12^{a}
MPB: with κ-C and XG	2.12^{b}	3.15^{b}	7.25^{a}	6.60^{a}	8.35^{a}	3.22^{b}	6.42^{a}	6.25^{a}	6.35^{a}	1.94^{b}	7.38^{b}	7.15^{a}	1.82^{b}
F values	334.49	2536.26	2187.64	2705.28	1.36	206.28	2912.99	1649.01	3332.61	130.82	154.41	127.51	70.39
C: Freeze/thaw cycle													
FMP: freshly made samples	2.91^{a}	4.72^{a}	6.31^{a}	5.17^{b}	8.09^{b}	4.30^{a}	4.96^{b}	5.04^{b}	5.13^{a}	2.50^{a}	7.68^{a}	6.99^{a}	2.29^{a}
F/TMP: frozen/thawed samples	2.10^{b}	4.41^{b}	5.62^{b}	5.31^{a}	8.67^{a}	3.94^{b}	5.16^{a}	5.15^{a}	4.52^{b}	1.74^{b}	7.71^{a}	6.70^{b}	1.66^{b}
F values	381.71	31.04	160.36	6.94	207.24	8.34	15.84	3.92	136.05	578.82	0.34	28.71	305.51
Interactions	*F* values												
AB	68.94	43.11	78.64	21.22	6.87	36.76	17.25	25.05	33.17	65.42	16.50	70.28	54.16
AC	103.88	26.05	51.80	14.15	12.23	31.19	27.85	9.28	22.04	56.98	22.07	23.52	58.56
BC	0.79	81.14	151.87	20.15	10.68	19.95	96.52	12.02	37.36	111.31	1.74	220.93	45.28
ABC	18	8.62	44.21	16.85	6.84	9.62	11.11	18.50	16.60	49.15	15.65	35.76	9.99

$^{a-f}$Means for each textural attribute and for the same factor with common superscripts did not differ significantly ($P \geq 0.05$); INL, inulin; EVOO, extra virgin olive oil; LSD, least significant difference; MP, mashed potatoes.

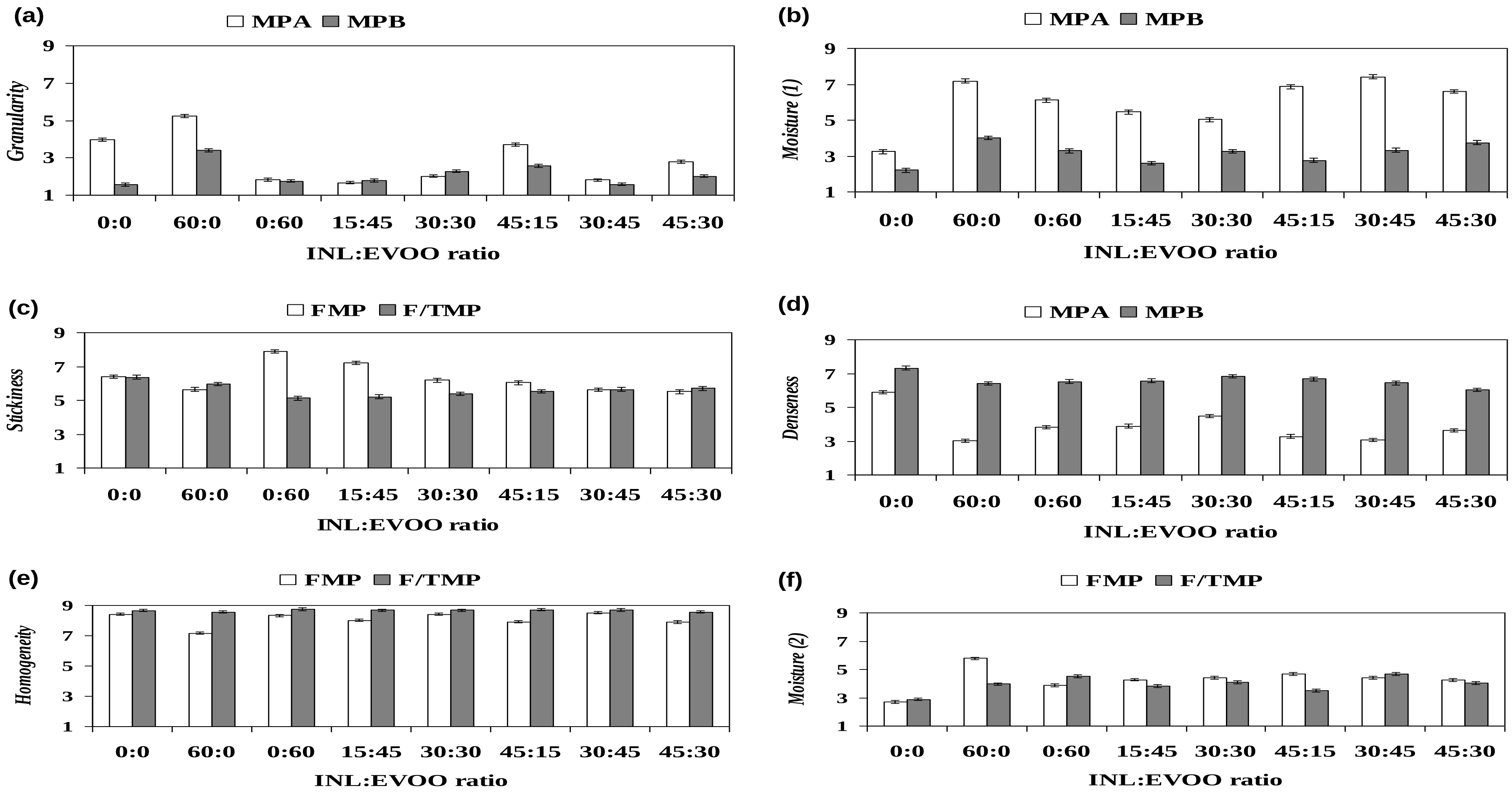

FIG. 1. SENSORY TEXTURE ATTRIBUTES SCORED BY THE TRAINED PANEL: **(a) Granularity; (b) Moisture (1); (c) Stickiness; (d) Denseness; (e) Homogeneity; (f) Moisture (2). MPA, MPB: mashed potatoes without and with added cryoprotectans respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes respectively. INL, EVOO: inulin and extra virgin olive oil.**

Attributes Perceived during Final and Residual Phases of Mastication. Variations in the ease of swallowing scores for INL:EVOO ratios of both MPA and MPB samples (Fig. 2e) show that in both types the scores increased when INL and EVOO were present, whether added singly or in blended samples. However, at a fixed total concentration the ease of swallowing scores were higher in both MPA and MPB samples with lower INL concentrations (0:60, 15:45 and 30:30 ratios). Fat is a well-known enhancer of the creaminess sensation,[29] coating the oral tissues and thereby reducing the friction between food and tissue. In this study, the main differences between samples with and without added EVOO were ascribed to either an aromatic or a creamy mouthfeel detected in the MP samples with added oil, with or without I. On the other hand, except in the samples with addition ratios of 15:45, 30:45 and 45:30, the MPA samples scored higher for ease of swallowing (Fig. 2e). This result was probably related to excessive thickening perceived by the panelists in the samples containing cryoprotectants. The effect of κ-C on product thickening could also be ascribed to the interaction of κ-C with denatured milk protein.[12] The panelists also gave significantly higher scores for palate coating to samples with added EVOO than for those without added EVOO (Table 2). Palate coating scores for MPA samples decreased after a freeze/thaw cycle, whereas the scores for MPB samples increased after processing with respect to the scores awarded to fresh products (Fig. 2f). This was probably due to softening in MPA and hardening in MPB samples after freezing and thawing processes. As a high correlation was found between the sensory attributes fibrousness (1) and fibrousness (2), graphs for fibrousness (2) scores have been omitted.

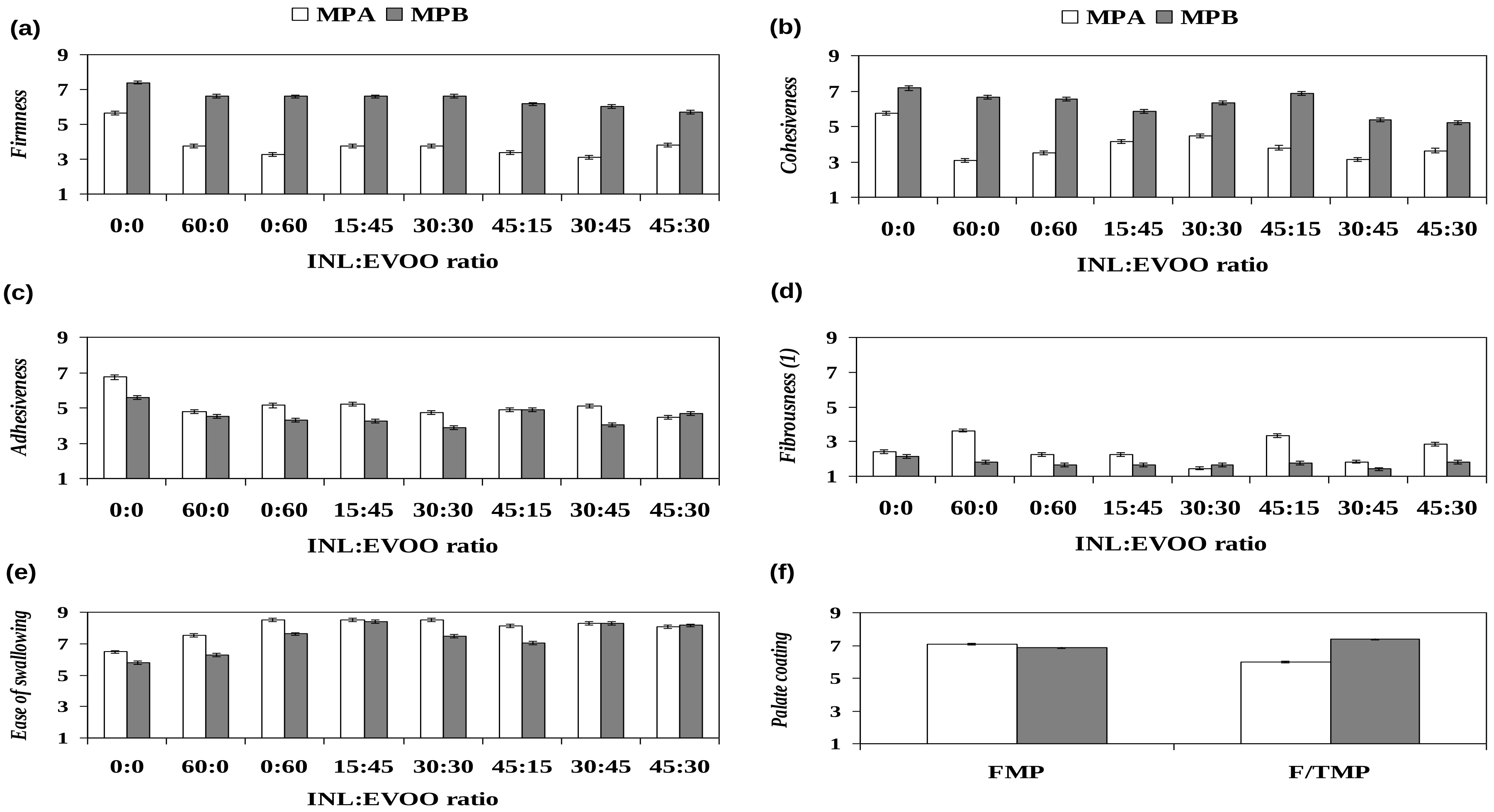

FIG. 2. SENSORY TEXTURE ATTRIBUTES SCORED BY THE TRAINED PANEL: **(a) Firmness; (b) Cohesiveness; (c) Adhesiveness; (d) Fibrousness; (e) Ease of swallowing; (f) Palate coating. MPA, MPB: mashed potatoes without and with added cryoprotectans respectively; FMP, F/TMP: fresh and frozen/thawed mashed potatoes respectively. INL, EVOO: inulin and extra virgin olive oil.**

Principal Component Analyses (PCAs) of Sensory Scores

Abbreviations for sensory attributes, as shown in Table 1, are used in this subsection mainly for the sake of brevity. As the method proposed by Dijksterhuis[33] was used to evaluate panel consonance, an independent PCA was carried out of the total dataset (n = 256) for each attribute (4 panelists and 64 samples) obtained from the conventional profile. High consonance coefficients (the ratio between the first eigenvalue and the sum of the others) indicate one-dimensional solutions or, in other words, that the panelists use the attribute in a similar way. Some differences were found between attributes. With four attributes (Sti, Adh, Eas and Pal) the solutions were multidimensional, with low consonance coefficients (0.58, 0.64, 0.55 and 0.53 respectively) and with the second eigenvalue almost as high as the first one. Moi (1) and Coh showed medium consonance coefficients (0.78 and 0.75 respectively). For the remaining 7 attributes the consonance coefficients were high and the second eigenvalue considerably lower than the first one. The highest coefficients were recorded for Fib (1) and Fib (2) (0.97 and 0.86 respectively). All this suggests an acceptable level of consonance between panelists although more training in the use of Sti, Adh and residual attributes (Eas and Pal) could improve the results.

Table 3 shows the two components extracted in each PCA analysis (total dataset and FMP, F/TMP, MPA and MPB subgroups considered separately) for all the thirteen sensory attributes. The eigenvalues of the third component were lower than 1.0 in all the cases. Figs. 3 and 4 show the biplots of the two principal components for the sensory attributes. PCA revealed that two principal components accounted for >74% of the total variability (Table 3) when all the data were included in the PCA analysis (Fig. 3), whereas the total variability explained by the first and second axes was slightly higher (>75%) when FMP and F/TMP samples were considered (Figs. 4a, 4b) separately, and slightly lower (<72%) when MPA and MPB samples were considered (Figs. 4c, 4d) independently.

TABLE 3. PRINCIPAL COMPONENT ANALYSES AND EQUATIONS OF THE PRINCIPAL COMPONENTS OF THE FIVE PCA ANALYSES CARRIED OUT.

	All total dataset		FMP samples		F/TMP samples	
Component number	Eigenvalue	Percent of variance	Eigenvalue	Percent of variance	Eigenvalue	Percent of variance
1	6.36	48.94	6.19	47.58	7.16	55.06
2	3.29	25.30	3.90	30.03	2.64	20.33

	MPA samples		MPB samples	
	Eigenvalue	Percent of variance	Eigenvalue	Percent of variance
1	5.13	39.48	4.87	37.43
2	4.17	32. 80	3.13	24.10

	All total dataset		FMP samples		F/TMP samples	
	Component 1	Component 2	Component 1	Component 2	Component 1	Component 2
Gra*	0.19	**-0.41**	0.20	**-0.38**	0.19	**0.46**
Moi (1)	**0.36**	0.05	**0.37**	-0.02	**0.33**	-0.18
Sti	**-0.30**	-0.10	**-0.33**	-0.00	**-0.29**	0.10
Den	**-0.37**	-0.11	**-0.38**	-0.13	**-0.35**	0.08
Hom	-0.10	**0.37**	-0.09	**0.34**	-0.09	-0.04
Moi (2)	**0.35**	0.01	**0.35**	-0.06	**0.32**	-0.20
Fir	**-0.37**	-0.09	**-0.37**	-0.10	**-0.36**	0.09
Coh	**-0.36**	-0.14	**-0.36**	-0.15	**-0.35**	0.10
Adh	**-0.34**	-0.20	**-0.36**	-0.16	**-0.34**	0.10
Fib (1)	0.16	**-0.44**	0.10	**-0.43**	0.27	**0.33**
Eas	0.17	**0.32**	0.14	**0.35**	0.17	**-0.40**
Pal	-0.14	**0.30**	-0.04	**0.41**	-0.22	**-0.40**
Fib (2)	0.15	**-0.46**	0.13	**-0.43**	0.16	**0.50**

	MPA samples		MPB samples	
	Component 1	Component 2	Component 1	Component 2
Gra	-0.05	**0.44**	**0.36**	0.14
Moi (1)	**0.37**	0.13	**0.34**	-0.09
Sti	-0.07	-0.26	0.13	**0.46**
Den	**-0.40**	-0.06	-0.24	0.29
Hom	-0.05	**-0.35**	**-0.37**	-0.01
Moi (2)	**0.34**	0.19	0.25	-0.08
Fir	**-0.41**	-0.03	**-0.30**	**0.30**
Coh	**-0.38**	-0.08	-0.11	**0.44**
Adh	**-0.39**	-0.03	0.12	**0.41**
Fib (1)	0.27	**0.44**	**0.38**	0.09
Eas	0.11	**-0.29**	0.00	**-0.44**
Pal	0.11	**-0.29**	-0.28	-0.07
Fib (2)	-0.12	**0.43**	**0.38**	0.10

***Identification of sensory attribute abbreviations in Table 1.**

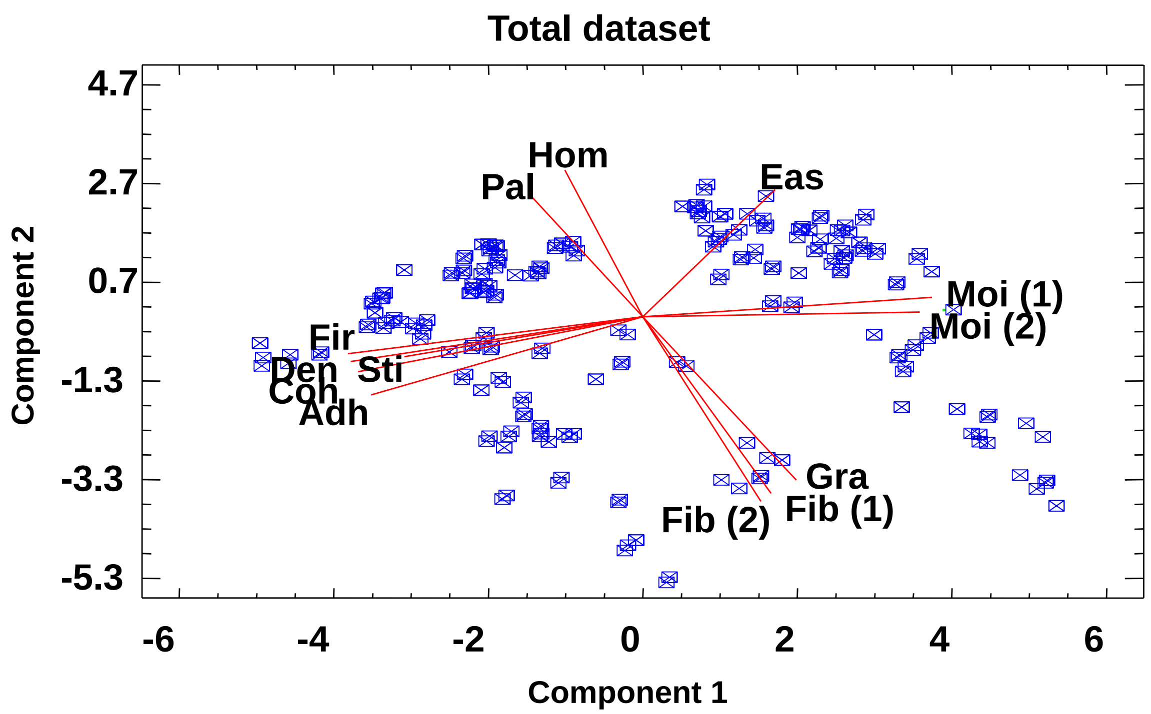

FIG. 3. BIPLOT FOR THE FIRST TWO PRINCIPAL COMPONENTS FROM THE PRINCIPAL COMPONENT ANALYSIS (PCA) CARRIED OUT FOR THE FULL DATASET. Identification of sensory attribute abbreviations in Table 1.

Table 3 also gives the weights of the linear combinations that make up the two principal components. Sensory attributes with the highest loadings for each component are marked in boldface, indicating that this component is dominated by these particular attributes. When the thirteen attributes were taken into account for all the data, including all experimental conditions (Fig. 3), Sti, Den, Fir, Coh and Adh weighted component 1 negatively, whereas Moi (1) and Moi (2) weighted the first component positively. Therefore, the most important attribute variations were shown by MP samples to be low values for both mechanical (stickiness, firmness, cohesiveness and adhesiveness) and geometrical (denseness) properties contrasting with high surface property values (moistures (1) and (2)). Adhesive MP samples had low moistness, which is common in potato textures.[34] Component 1 was mainly a contrast between the mechanical (Sti, Fir, Coh, Adh) and surface texture attributes (Moi (1), Moi (2)), and acted as an index of the mechanical behavior and moistness of the product. On the other hand, intercorrelated sensory attributes with nearly equal loadings were assumed to represent some redundancy. Den, Fir and Coh in particular had nearly equal loadings, and Moi (1) and Moi (2) explained the same characteristic.

Component 2 was positively weighted by Hom, Eas and Pal and negatively dominated by Gra and both Fib (1) and Fib (2). This means that when the panelists detected more granularity and fibrousness, they detected poorer homogeneity, ease of swallowing and palate coating. Component 2 integrates four geometrical attributes (Gra, Hom, Fib (1) and Fib (2)) associated with the arrangement of particles in the product, and surface roughness or smoothness properties of MP texture according to Szczesniak.[7] Hence, component 2 may be identified mainly with geometrical and residual textural attributes which serve as an index of the roughness/smoothness of the MP samples. Note that although Den is a geometrical attribute, it correlated strongly with two mechanical properties (Fir and Coh). This indicated that the panel had difficulty to distinguish between force (Coh) and deformation (Fir) of the mechanical properties and between solidness (Den) of the geometrical ones. The level of representation of an original attribute in the first and second principal component planes (Fig. 3) can be measured by means of the cumulative determination coefficient, defined as commonalities (data not shown). Firm, Coh and Adh, in that order, were the most important of the mechanical sensory attributes, explained to a great extent by the first two principal components, whereas geometrical Hom and residual Eas and Pal were only explained to a fairly moderate extent (with low percentages).

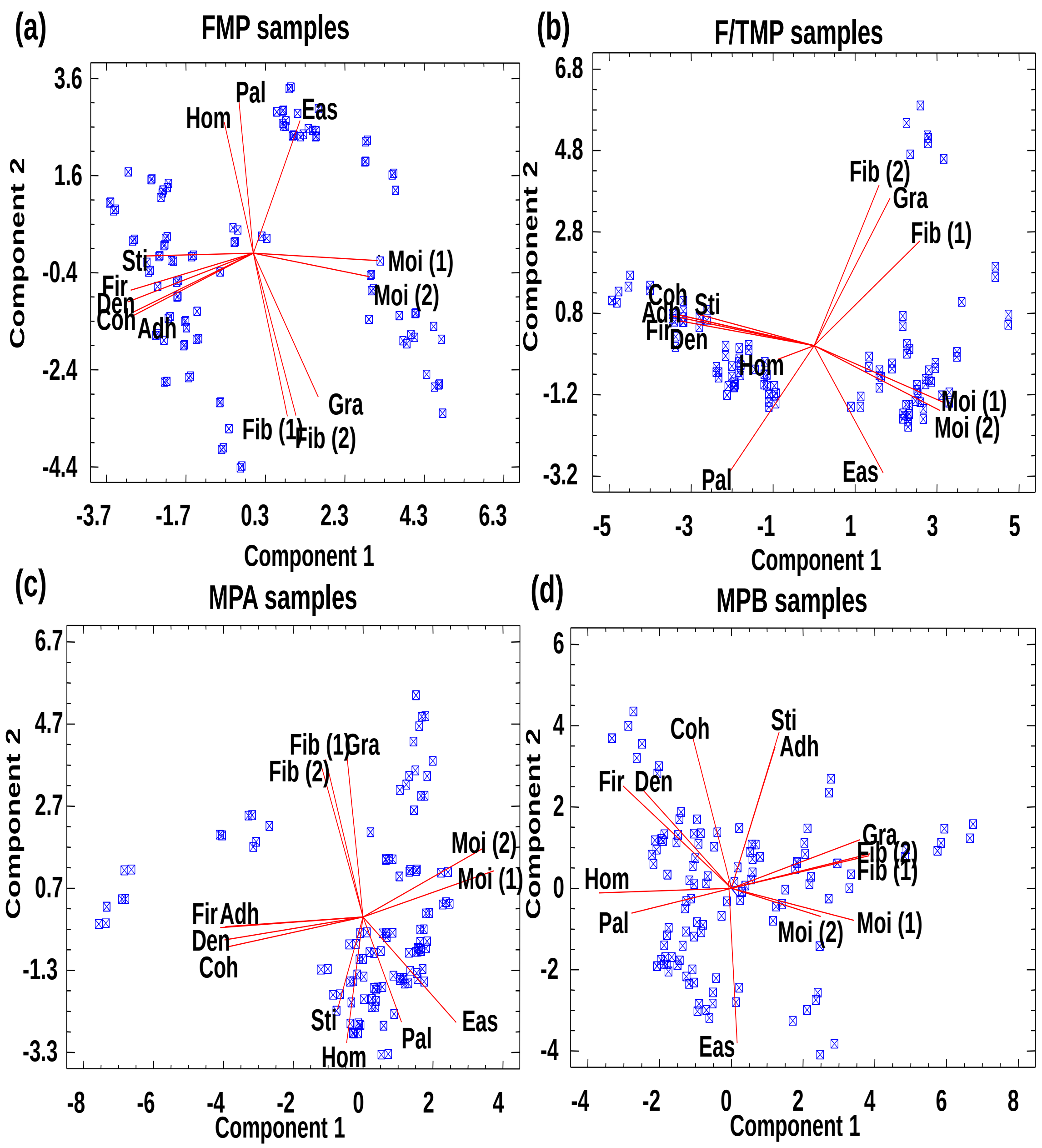

FIG. 4. BIPLOT FOR THE FIRS TWO PRINCIPAL COMPONENTS FORM THE PRINCIPAL COMPONENT ANALYSES (PCAs) CARRIED OUT FOR: (a) FMP samples; (b) F/TMP samples; (c) MPA samples; (d) MPB samples. FMP, F/TMP: fresh and frozen/thawed mashed potatoes respectively; MPA, MPB: mashed potatoes without and with added cryoprotectants respectively. Identification of sensory attribute abbreviations in Table 1.

It is worth noting that when considering only FMP samples, both components are dominated by the same sensory attributes (Fig. 4a, Table 3). In this case geometrical Den and mechanical Adh were the attributes best explained by the two components, whereas explanation percentages for Hom and Eas were the lowest. Then again, if we consider F/TMP samples separately (Fig. 4b, Table 3), Sti, Den, Fir, Coh and Adh also negatively weighted component 1, whereas it was positively weighted by Moi (1) and Moi (2), the same as in the PCA analyses with the complete dataset and with FMP samples; MP samples had high moistness but low levels of Sti, Den, Fir, Coh and Adh. However, Eas and Pal strongly weighted component 2 negatively, which in this case, was positively dominated by Gra and Fib (2). MP is a starchy food and as such may present quality problems such as syneresis, organoleptic and textural changes, especially if subjected to freeze-thaw cycles. These problems have been ascribed to phase separation caused by starch retrogradation.[21] Therefore, this change in the sign of the sensory attributes weighting component 2 is likely related to starch retrogradation caused by the freezing process in the products without added cryoprotectants, and consequently the panelists gave them higher scores for granularity and fibrousness. Of the mechanical attributes, Fir was the one best explained by the first two principal components and may therefore be considered the best suited to evaluate MP texture in the F/TMP samples.

In the case of the MPA samples (Fig. 4c, Table 3), again Moi (1) and Moi (2) positively weighted the first component, whereas it was weighted negatively by Den, Fir, Coh and Adh. Also, as in the F/TMP samples, Gra, Fib (1) and Fib (2) positively weighted the second component, whereas it was negatively weighted by Hom, Eas and Pal. Curiously, Fib (1) was the most important sensory attribute in this case, explained to a great extent by the first two components. This result therefore confirms that the absence of κ-C and XG in the frozen/thawed systems increased visual granularity.

However, if we consider the MPB samples separately (Fig. 4d, Table 3) we find a change in the correlations of the sensory attributes with both components, probably due to a reduction or absence of starch retrogradation. As mentioned above, gums like XG affect starch gelatinization through strong associations with amylose, resulting in reduced starch retrogradation.[26] Gra, Moi (1), Fib (1) and Fib (2) positively weighted component 1, whereas it was negatively weighted by Hom in particular; this factor is negatively dominated by Hom and almost equally weighted on the Gra, Fib (1) and Fib (2) ratings. Hence, component 1 is identified in this case with the geometrical attributes detected either before putting the sample in the mouth or during the final and residual phases of mastication, serving as an index of the roughness/smoothness of the MP samples. Also, Sti, Coh and Adh in particular, positively weighted component 2, though this factor was negatively dominated by Eas. In the MPB samples, component 2 was mainly a contrast between the mechanical texture attributes of the MP samples perceived during chewing versus residual ease of swallowing. MP samples with high levels of Coh, Sti and Adh had low Eas. Here again, Fib (1) and Fib (2) had equal loadings (Table 3) as they explained the same characteristic. In the MPB samples, Fib (2), Fib (1) and Sti were the sensory attributes best explained by the two components (in that order). Certainly, new PCA analyses were run when redundant attributes were eliminated in any analysis, but these data are not shown for the sake of brevity. The main point of interest is that Fib (2) and Moi (2) in particular could be removed with only a small percentage loss of information.

Influence of Composition and a Freeze/Thaw Cycle on Instrumental Texture Measurements and E_w of MP Samples

Table 4 shows the effects of the INL:EVOO ratio, cryoprotectant addition and a freeze/thaw cycle on the values of the instrumental texture measurements derived from the BE tests and E_w values. The analysis of variance showed that the three factors under consideration and their binary interactions had a significant effect on both instrumental texture measurements. This means that the effect of the INL:EVOO ratio on instrumental texture was dependent on the presence of κ-C, XG and a freeze/thaw cycle. Plots for the BE viscosity index have been omitted for the sake of brevity.

TABLE 4. EFFECTS OF INL:EVOO RATIO, CRYOPROTECTANT ADDITION AND A FREEZE/THAW CYCLE ON MEAN VALUES OF INSTRUMENTAL TEXTURE MEASUREMENTS AND EXPRESSIBLE WATER FOR MP SAMPLES. Means and F values.

Source	BE firmness (N)	BE viscosity index (N s)	E_w (%)
Main effects:			
A: INL:EVOO ratio			
0:0 control	7.04[a]	-37.06[a]	17.32[e]
60:0	5.17[b]	-23.65[b,c]	28.91[a]
0:60	4.67[d]	-23.16[c,d]	16.20[e]
15:45	4.83[c,d]	-24.59[b]	20.60[d]
30:30	4.92[c]	-23.92[b,c]	20.35[d]
45:15	5.19[b]	-24.66[b]	25.68[b]
30:45	4.21[e]	-20.65[e]	19.50[d]
45:30	4.61[d]	-22.65[d]	23.63[c]
F values	212.59	290.46	164.39
B:Cryoprotectant addition			
MPA: without κ-C and XG	4.64[b]	-21.28[b]	-
MPB: with κ-C and XG	5.52[a]	-28.73[a]	-
F values	460.78	1265.80	-
C:Freeze/thaw cycle			
FMP: freshly made samples	5.50[a]	-25.60[a]	26.09[a]
F/TMP: frozen/thawed samples	4.66[b]	-24.41[b]	16.96[b]
F values	419.24	32.35	1489.97
Interactions	*F* values		
AB	34.25	29.32	-
AC	10.95	10.15	22.02
BC	932.54	817.12	-
ABC	10	22.03	-

[a-e]Means for each instrumental measurement and for the same factor with common superscripts did not differ significantly ($P \geq 0.01$); INL, inulin; EVOO, extra virgin olive oil; LSD, least significant difference; MP, mashed potatoes.

Maximum instrumental texture values were registered in a 0:0 control (Table 4). By adding 60 g/kg of INL alone (60:0 ratio) all the instrumental measurements were significantly reduced when compared with the 0:0 control, whereas adding 60 g/kg of EVOO alone (0:60 ratio) significantly reduced instrumental BE firmness as compared to the addition of 60 g/kg of INL alone. This indicates that EVOO addition alone produced softer systems than INL addition alone. However, variations in the BE firmness value based on the INL:EVOO ratios in both MPA and MPB samples (Fig. 5a) show that in all cases (except for 0:0 control) BE firmness was lower in the MPA than in the MPB samples; moreover, the variation in the firmness of the samples with both ingredients was much greater in the case of the MPA samples. Only MPB samples with addition ratios of 30:45 and 45:30 (at a higher total concentration, 75 g/kg) had significantly lower BE firmness values than those with a lower fixed total concentration (60 g/kg). The presence of hydrocolloids resulted in an improved, more solid, reinforced three-dimensional network structure, possibly through the exclusion effect of swollen starch granules promoting κ-C gelation in the aqueous phase. κ-C provided the appropriate texture, while XG imparted creaminess to the product.[12] Analogously, in starch/XG blends, it was observed that XG does not interfere with potato starch network building.[35, 36]

The differences in BE firmness values between MPA and MPB samples were lower when INL was added at the higher concentrations (60:0, 45:15 and 45:30 ratios). Therefore, in the absence of κ-C and XG, INL addition at concentrations above 45 g/kg (either alone or blended with EVOO) produced a thickening effect on the MP as compared to I addition at lower concentrations. It is possible that in MPA samples, the structure of the MP was thickened due to the high INL concentration, because the system had enough particles and/or sufficient molecular INL chain density to reach a critical crowding effect.[4, 30] This speculation is in agreement with the microstructure observed in INL-EVOO-based MP samples,[37] where amylose/amylopectin form a rigid matrix in which I particles are trapped. Guggisberg *et al*. [38] showed that even though firmness and creaminess of low-fat set yogurt increased with both INL and fat content, the highest level of INL considered (4%) was not enough to imitate the whole-milk yogurt. In turn, Villegas and Costell[5] observed that low-fat milk beverages with a similar thickness and creaminess to those perceived in whole-milk beverages could be obtained by adding long-chain INL at a concentration above 8%. Of the MPA samples with added INL:EVOO, the ones with the lowest EVOO concentration (45:15 ratio) were firmest (Fig. 5a). At a fixed EVOO concentration, the firmness of the MPB samples decreased significantly with increasing INL concentrations (15:45 vs 30:45 and 30:30 vs 45:30 ratios); whereas at a fixed INL concentration, the addition of EVOO at higher concentrations considerably reduced BE firmness in both MPA and MPB samples (30:30 vs 30:45 and 45:15 vs 45:30 ratios). Both ingredients caused softening of the MP samples, but when they were added in blends, the degree of softening was more dependent on EVOO concentration. In oil/water emulsions, the extent of the linear region has been reported to decrease with increasing oil-phase volume fraction from 20% to 40% v/v.[39]

When INL/EVOO blends were added to MP, the BE firmness value behaved similarly in the FMP and F/TMP samples (Fig. 5b). In natural MP the product was also softer than the fresh control after freezing and thawing.[10] When compared with samples with added INL alone, the differences in firmness between fresh and frozen/thawed samples were greater in samples with INL/EVOO blends. Probably, the structural damage caused by freezing enabled the oil droplets to come close enough together to aggregate through steric and/or electrostatic forces.[40] Variations in BE firmness based on a freeze/thaw cycle showed that the BE firmness value developed differently for MPA and

MPB samples (Fig. 5c). Freezing and thawing significantly reduced sample firmness in the MPA samples but significantly increased it in MPB samples. This difference can be explained if we consider that much stronger and more cohesive networks are formed when solutions of XG are frozen and thawed.[41] The effect of XG may be explained by amylose/XG interactions, which compete against amylose/amylose interactions, retarding or even preventing retrogradation. Also, the addition of small amounts of XG has been reported to significantly improve freeze/thaw stability of white sauces made with starches from different sources.[29]

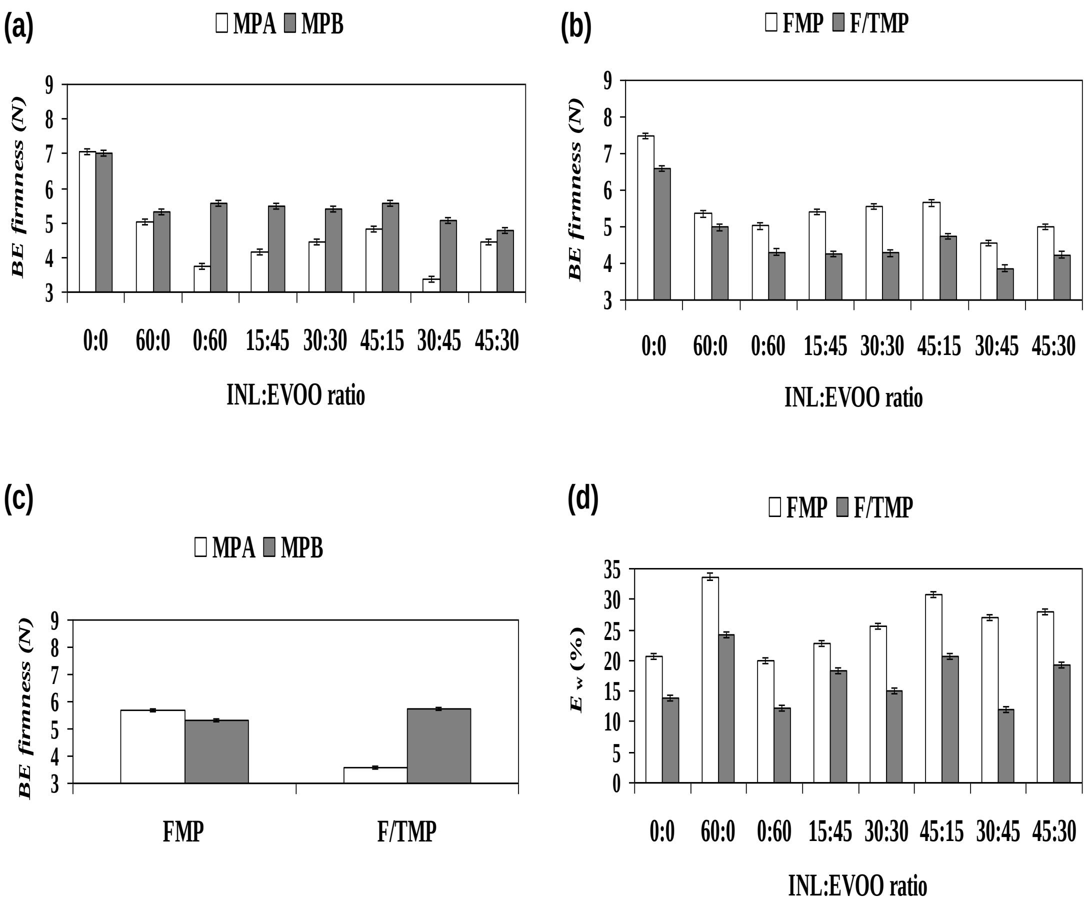

FIG. 5. INSTRUMENTAL TEXTURE MEASUREMENTS AND EXPRESSIBLE WATER: (a-c) Back extrusion (BE) firmness; (d) Expressible water (E_w). MPA, MPB: mashed potatoes without and with added cryoprotectants respectively; FMP, F/TMP: fresh and frozen /thawed mashed potatoes respectively. INL, EVOO: inulin and extra virgin olive oil.

E_w value variations for different INL:EVOO ratios of both FMP and F/TMP samples are shown in Fig. 5d. In both FMP and F/TMP samples, at a fixed total concentration, the highest and lowest E_w values were registered in samples with addition ratios of 60:0 and 0:60 respectively. Furthermore, in the FMP products the water holding capacity (WHC) decreased linearly with increasing INL content (0:60, 15:45, 30:30 and 45:15 ratios), probably due to large INL particles occupying the interchain spaces and, displacing the water. Nevertheless, EVOO by itself did not affect the WHC of MP systems (Table 4). Besides, E_w was greater in the FMP samples than in their F/TMP counterparts in all cases. This is related in part to water loss occurring in the frozen/thawed samples through recrystallization and sublimation phenomena. However, these results also suggest that cooling prior to freezing, as well as freezing itself, might have favored conformational changes in the INL molecules, which in turn would have resulted in a smaller solid particle size and a larger surface exposed to interaction with water.[42] This could account for the superior water retention detected in the F/TMP samples. Moreover, as long-chain INL particles are only held together by physical interaction between molecules,[43] the mechanical strength of the crystallized INL particles might have been too low to support the stresses caused by ice crystal growth during freezing. Also, in these systems there could have been sedimentation of INL crystals as a result of decreasing temperature[44] and subsequent recrystallization during thawing and heating. After freezing, enough water may be present to allow a small fraction of INL to recrystallize with different solubility properties.

After a complete dependence study which was carried out on the sensory attribute scores versus instrumental texture measurements, low correlations between instrumental and sensory ratings were found. Previous publications by other researchers generally agreed on good to excellent correlations for hardness (based on calculated "*r*" values),[7] which contrasts with correlations for other parameters that are usually mediocre and product dependent. In this study, when considering different subgroups separately, relatively high correlations with sensory firmness scores were found in the case of BE firmness, so that relationships were statistically significant as linear functions. The best correlation was found between BE firmness and perceived firmness when the F/TMP samples with added cryoprotectants were considered separately (R^2 = 0.88). Differences in thickness observed among samples were explained by BE firmness, but not the variation in other surface and geometrical textural attributes, determining sample creaminess. Certainly, although mechanical and rheological properties are the predominant stimuli affecting texture perception in most foods, results indicate that in the case of MP samples, matching rheological behavior with perceived texture is not guaranteed, as reported by Bayarri *et al*.[28]

CONCLUSIONS

Mechanical texture properties have confirmed that both INL and EVOO can be considered as soft fillers suspended and entrapped in a rigid amylose/amylopectin matrix respectively. The most obvious difference was observed between 0:0 control and samples containing 15:45 and 30:45 ratios, which was ascribed mainly to the fact that the samples containing higher EVOO concentrations received lower granularity scores. In FMP samples, the sensory texture profile of products with an added 30:30 ratio was similar to that of the product without added ingredients. This result has important consequences for the formulation of MP with added inulin and extra virgin olive oil blends, since the food industry places particular emphasis on the development of foods that have the same desirable quality attributes as the original product. On the contrary, in both F/TMP and

MPA samples considered separately, the texture profile of the product without added ingredients was very different from that of MP samples containing INL and EVOO, whether added singly or in associated blends. If the product is to be frozen, and therefore contains cryoprotectants, κ-C and XG mask the effect of adding different INL/EVOO blends on the texture profile of the MP samples, probably due to the water holding capacity conferred by XG. PCA of the total dataset and FMP, F/TMP and MPA samples considered separately showed that component 1 served as an index of the mechanical behavior and moistness of the product, whereas when MPB samples were analyzed separately, the first principal component served as an index of the roughness/smoothness in response to reduced starch retrogradation in the presence of κ-C and XG. Although the level of consonance between panelists was acceptable, better results could have been achieved with more training in the use of stickiness, adhesiveness, ease of swallowing and palate coating. Furthermore, the results suggest that there is an overlap between moisture (1) and moisture (2), between fibrousness (1) and fibrousness (2) and between stickiness and adhesiveness. Certainly, more work is needed on reselection of some sensory attributes.

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TEXTURE PERCEPTION DETERMINED BY SOY PROTEIN ISOLATE AND INULIN ADDITION IN POTATO PUREE: LINKS WITH MECHANICAL AND MICROSTRUCTURAL FEATURES.

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ABSTRACT

This study evaluated the effect of adding soy protein isolate (SPI) and long-chain inulin (INL) blends with 10 different SPI:INL ratios on the textural, rheological and microstructural properties of freshly made and frozen/thawed potato puree. All the potato puree samples were subjected to a sensory texture profile analysis and a trained panel rated the intensity of six descriptors, while an untrained panel did the same on six selected frozen/thawed products. The main SPI:INL ratio effect remained significant for all the descriptors evaluated, when the analysis of variance was applied considering the untrained assessors as random effects. However, only trained panel scores for creaminess corresponded well with untrained assessor ratings. Rheological flow index values were linked with variations in perceived consistency, and geometric and surface textural attributes were explained by structural features such as the presence of INL crystallites and SPI coarse strands.

KEYWORDS

Flow behavior, long-chain inulin, microstructure, soy protein isolate, texture perception, trained and untrained panel

PRACTICAL APPLICATIONS

A potato puree (PP) serving of 200 g with added soy protein isolate (SPI) and/or inulin (INL) concentrations of 1.5-6% provides from 3 to 12 g of SPI and/or INL, respectively. The presence of SPI strands is a dominant factor in texture perception of PP with regards to mouthfeel geometric attributes (visual graininess and fibrousness) and the afterfeel attribute (mouth coating), while INL crystallites are the most important feature influencing creaminess. By adding small amounts of SPI (1.5%) together with INL at >3% increases the intensity of perceived creaminess, which was the most important descriptor in practical terms. In view of the foregoing, PP with added SPI and INL is a promising foodstuff for incorporating into a diet and in addition, even improves product structure.

INTRODUCTION

Food texture is defined as "all the rheological and structural (geometric and surface) attributes of the product perceptible by means of mechanical, tactile and, where appropriate, visual and auditory receptors" (Foegeding *et al*. 2011). Many instrumental methods are geared to determining rheological characteristics of food products (Wilkinson *et al*. 2000). Nevertheless, Heath and Lucas (1987) recognized that advances in understanding texture perception would depend on a multidisciplinary approach considering sensory research, physiology and research into food structure.

Basically, potato puree (PP) is formulated with native potato starch (Alvarez *et al*. 2009), and this starch-based food can be considered as a semisolid or soft-solid, viscoelastic material (Foegeding *et al*. 2011). Changing their composition by adding new ingredients would result in texture changes of the final product. Soy protein isolate (SPI) is an ingredient that can improve the organoleptic characteristics and nutritional value of food products (Tseng *et al*. 2009). Because of the health benefits of inulin (INL) in the human diet, much research has focused on this ingredient (Bot *et al*. 2004; González-Tomás *et al*. 2008).

The classification of textural terms for solids and semisolids gave rise to a profiling method of texture description (Texture Profile Analysis [TPA]) (Szczesniak 2002), providing qualitative and quantitative measures of a product's characteristics. Qualitative component comprises the descriptive terms which define the sensory profile of the product, while quantitative component measures the intensity of each attribute perceived to be present (Carlucci and Monteleone 2001).

Starch-based products have been characterized by sensory descriptors such as mouth coating, creaminess, or thickness (De Wijk *et al*. 2003, 2006). High-fat custards produced less sensation of dryness and fibrousness, and more sensations of flavor, creamy, fatty mouthfeel and after-feel than their zero fat-containing counterparts (De Wijk *et al*. 2003). Addition of olive oil enhanced the PPs sensory quality reducing granularity, denseness, cohesiveness, adhesiveness and fibrousness, and increasing homogeneity, ease of swallowing and palate coating (Alvarez *et al*. 2011b).

Two types of panels are used, namely the trained profile panel, commonly modeled after the General Foods Texture Profile Panel (Cardello *et al*. 1985) and the consumer panel, used frequently for obtaining hedonic texture measures. Research on starch-based foods is mostly conducted to study sensory characteristics rated by trained panels. However, no research has been conducted to assess the relationships between judgments of the perceived texture of starch-based foods by trained and untrained panelists. Moreover, in many research papers, a description of the model of analysis of variance (ANOVA) used is often ignored, even though there are two main ANOVA models (Næs and Langsrud 1998). Assessors should be considered as fixed parameters to analyze the type of individual differences, but as random variables to validate product differences (Carlucci and Monteleone 2001).

The first objective of this study was to evaluate the effect of the SPI:INL ratio and a freeze/thaw cycle on the perceived texture of PPs supplemented with different SPI/INL blends using a statistical approach to validate product differences as well as trained and untrained panel performances. A second objective was to study as to what extent the perceived texture in these systems is related to rheological flow properties and microstructural features.

MATERIALS AND METHODS

Materials

The potatoes used were tubers (cv Kennebec) from Aguilar de Campoo (Burgos, Spain). Readily dispersible SPI **(**PRO-FAM 646, ADM, Netherlands) was used without further purification. INL (Orafti HP, BENEO-Orafti, Tienen, Belgium) was a “long-chain” INL with a degree of polymerization, DP ≥ 23 and 99.5% purity (producer’s data). *κ*-C (GENULACTA carrageenan type LP-60) and XG (Keltrol F [E]) were donated by Premium Ingredients, S.L. (Girona, Spain). Eight SPI:INL ratio blends were added to samples: 1.5:4.5 (that is 1.5%, of the total raw ingredients, [SPI]/4.5% [INL]), 3:3, 4.5:1.5, 1.5:6, 3:4.5, 4.5:3, 6:1.5 and 6:6. Samples without added ingredients (0:0 control), with 6% added INL alone (0:6) and with 6% added SPI alone (6:0) were also prepared for both fresh PP (FPP) and those subjected to a freeze/thaw cycle (F/TPP).

Preparation of PP Samples

Tubers were manually washed, peeled and diced. PP were prepared in ~1,350-g batches from 790 g of potatoes, 300 mL of semi-skimmed in-bottle sterilized milk, 200 mL of water, 10 g of salt (NaCl) and 1.95 g each of two hydrocolloids, *κ*-C and XG

(Premium Ingredients, L.L., Girona, Spain) (Alvarez *et al*. 2009), using a TM 31 food processor (Vorwerk España, M.S.L., S.C., Madrid, Spain). The INL (0-6%) was previously dissolved in the 300 mL of milk and 150 mL of water at 70C for 15 min and stirred constantly with a magnetic stirrer. The ingredients were first cooked for 30 min at 90C (blade speed: 40 rpm) and any evaporated water was replaced gravimetrically. At this point, SPI which had previously been hydrated at a ratio of SPI to water of 1:5 was added at 1.5-6%. Water used to hydrate SPI was removed from the initial water content (200 mL). Next, all the ingredients were cooked at 90C for 5 min. The mash was ground for 40 s (1,200 rpm) and 20 s (2,600 rpm), and then homogenized through a stainless steel sieve (diameter: 1.5 mm). Half of each fresh blend was analyzed immediately, and the other half was frozen and thawed. Freezing, thawing and heating procedures can be consulted (Alvarez *et al*. 2011a,b). Sample testing temperature was 55C as this is the preferred temperature for PP consumption.

Sensory Evaluation

PP samples which were subjected to sensory TPA, modified to evaluate vegetable purees according to UNE 87025 (1996) and other relevant International Standards (ISO 2008), were used to select and define the descriptors included in the profile. Profile attributes were classified into four groups (Fernández *et al*. 2008; Alvarez *et al*. 2011b), but only six selected descriptors were rated in this study (Table 1). Descriptors are listed in order of perception according to ISO guidelines (ISO 2003). A panel of four assessors, previously trained (ISO 1993), evaluated the descriptors of the samples.

Daily, for 44 days at a fixed time (1:00 p.m.), assessors were given one PP sample (about 50 g each), for scoring the attributes of the 22 samples, in duplicate. All the samples were served in white plastic vessels at a temperature of 55 ± 1C. For each sample, panelists evaluated the perceived intensity of the attributes on 8 cm descriptive linear scales labeled at each anchor: (left anchor: 1 = ‘‘not detectable”; right anchor: 9 = ‘‘extremely intense’’).

An untrained panel of 27 assessors (8 males, 19 females) rated the intensity of the descriptors on only six selected F/TPP samples, in triplicate, over six sessions and each panelists evaluated three samples per session. These samples were selected in order to be sure that the variation between them was sufficiently large (considerable differences can be observed between the microstructure of these samples; see Microstructure Examination subsection). At the start of each session, untrained panelists were given a printed response sheet with written instructions for the test, including the definition of each attribute to be judged during the session (Table 1), as well as the main adjectives corresponding to each anchor of the scale. In addition, untrained panelists were given a 20-min orientation session on the day before the test session; the panel leader explained the objectives of the study and untrained panelists were instructed to perform exactly the same sensory/psychophysics tasks than the trained panelists. These tasks included discussion in the rendering of operational definitions and scaling of each specific textural attribute. At each session, the untrained panelists were encouraged to refer to instructions and definitions of the attributes, and other spoken explanations were given to the panel when required. Moreover, each panelist was observed while he/she made the trial evaluations. The untrained panel had never previously evaluated PPs, although many had previously participated in making textural or other analytical sensory scores of a variety of foods. Definitely, the untrained panelist did not evidence difficulty to evaluate these descriptors in the six selected F/TPP samples. Similarly, samples were served at about 55 ± 1C in white plastic vessels, and the intensity of each attribute was scored as indicated above. Still mineral water was used as palate cleanser. The untrained panel was asked to score the overall acceptability (OA) of each sample based on texture, color and taste, on a 9-point hedonic scale (with 8 cm) labeled at each anchor: (left anchor: 1 = "dislike extremely"; right anchor: 9 = "like extremely").

TABLE 1. END TERMS AND DEFINITIONS OF THE DESCRIPTORS USED IN THE SENSORY EVALUATION OF POTATO PUREE

Descriptor	End terms	Definition
Visual graininess	Smooth-Grainy	Geometrical textural attribute reflecting the size and shape of the particles.
Creaminess	Not perceived-Intense	Combined perception of fat, smoothness and thickness.
Moisture	Dry-Watery	Surface textural attribute reflecting the water content of the potato puree.
Consistency	Thin-Thick	Mechanical textural attribute relating to the force required to achieve a given deformation, penetration, or breakage of the potato puree.
Fibrousness	Smooth-Grainy	Geometrical textural attribute reflecting the graininess perceived during preparation of the sample in the mouth prior to swallowing.
Mouth coating	Not perceived-Intense	Property reflecting the sensation of potato puree remaining on the palate after swallowing or ingestion.

Rheological Measurements

A Bohlin CVR 50 controlled stress rheometer (Bohlin Instruments Ltd., Cirencester, UK) was used to conduct steady flow tests using a plate-plate sensor system with a 2-mm gap (PP40, 40 mm) and a solvent trap to minimize moisture loss during tests. After loading the sample, a waiting period of 5 min allowed the sample to recover and reach 55C with a Peltier Plate system (-40 to +180C; Bohlin Instruments). In the flow test, shear stress was linearly increased until a shear rate of about 100/s was reached in about 5 min. Experimental data from ascending rheograms were fitted to the Ostwald de Waele model (Fernández *et al*. 2008), and consistency index (K, Pa·s^n) and flow behavior index (n) were obtained.

Apparent viscosity values at 50/s ($\eta_{app,50}$ [Pa·s]) would represent the approximate viscosity felt in mouth (Bourne 2002). Thus, apparent viscosity values at 50/s were estimated (Eq. 1) and associated with oral evaluation of consistency.

$$\eta_{app,50} = K \dot{\gamma}^{\,n-1} \qquad (1)$$

Kokini oral shear stress (σ_{oral} [Pa]) has been used as a physical index of the sensory perception of thickness (Bayarri *et al*. 2011). Therefore, n and K values were used to calculate the σ_{oral} and considered as an index of perceived thickness or consistency.

Scanning Electron Microscopy (SEM)

PP microstructure was examined by SEM using a Hitachi model S-2.100 microscope (Hitachi, Ltd., Tokyo, Japan). PP samples were air-dried, then mounted and sputter-coated with Au (200 A approx.) in a SPI diode sputtering system metallizer. Photomicrographs were taken with a digital system Scanvision 1.2 of Röntgenanalysen-Technik (800 ×1,200 pixel, Rontec, GmbH, Berlin, Germany).

Statistical Analysis

A three-way mixed-model ANOVA (SPI:INL ratio [S], treatment [T], i.e. performance or not of a freeze/thaw cycle and assessor [A]) with interactions was applied to the sensory descriptors evaluated by the trained panel, assuming that main effects and interactions were fixed effects. A two-way mixed-model ANOVA (SPI:INL ratio [S], treatment [T], and S × T) was also applied to the descriptors, likewise, ignoring random effects. Subsequently, a three-way mixed-model ANOVA was performed on the descriptors rated by the untrained panel to analyze the SPI:INL ratio, assessor (A) and replicate (R) effects and their interactions, again assuming that main effects and interactions were fixed effects. Next, a two-way mixed-model ANOVA (S, A and S × A) was applied, considering assessors and interaction as random effects (Carlucci and Monteleone 2001). Minimum significant differences were calculated using Fisher's least significant difference test (LSD; 95%).

In turn, a two-way mixed-model ANOVA (S, T and S × T) was applied to rheological data (n, K, $\eta_{app,50}$, and σ_{oral}). Significant differences were determined using Fisher's test (LSD; 99%). Correlations between descriptors rated by untrained and trained panels were determined by multiple regressions with confidence intervals of 95%. Pearson correlations were also established between rheological properties and perceived consistency rated by the trained panel. All analyses were performed using Statistical Package for the Social Sciences (SPSS) 19.0 software (SPSS, Inc., Chicago, IL).

RESULTS AND DISCUSSION

Sensory Properties Evaluated by the Trained Panel

The three-way mixed-model ANOVA showed a significant ($P < 0.05$) SPI:INL ratio and treatment main effects for all the descriptors (Table 2). Furthermore, S × T interactions were significant in all cases. Assessors were not significant for five descriptors, showing consistency between judges for these attributes. However, assessors were a significant source of variation in the case of fibrousness, indicating that additional training in the use of this descriptor could be needed. Even so, the effect of T × A and S × A interactions was not significant for all textural attributes, indicating a good level of agreement among the panel members regarding their evaluations. According to Carlucci and Monteleone (2001), as assessors were considered as fixed effects, no conclusions can be extended to the population from which the assessors were drawn.

Effect of the SPI:INL Ratio in the FPP and F/TPP Samples. After considering only S and T effects and their interaction, the two-way mixed-model ANOVA again showed that both main effects and interaction were a significant ($P < 0.05$) source of variation for all attributes (data not shown). Table 3 shows the mean values of each descriptor for both FPP and F/TPP samples. In the FPP samples, scores for graininess were very low and those for creaminess very high, for the control and all the samples with higher INL contents. However, by increasing SPI concentrations, perceived graininess increased and creaminess decreased. All the other FPP samples had significantly higher moisture and lower consistency scores when compared with the 0:0 control, indicating that either SPI or INL are hygroscopic ingredients and behaved as soft fillers. Exudation of the continuous liquid phase of gels during compression gives rise to watery/juicy sensory attributes (van Vliet *et al*. 2009), although the microstructural characteristics of the gels are also involved. Long-chain INL structure resembles that of a network of fat crystals in oil, since this type of INL forms small microcrystal aggregates that occlude a large amount of water, thereby creating a smooth and creamy texture (Bot *et al*. 2004; Guggisberg *et al*. 2009). Similarly, an important functional property in SPI is gelation during thermal treatment with desirable water holding capacity (WHC) (Tseng *et al*. 2009). However, FPP samples with an added 6:6 ratio had the lowest consistency score, suggesting that perceived water content is not the only factor influencing perceived consistency in FPP products.

Significantly, fresh 0:0 control and samples with added 0:6, 3:3 and 1.5:6 ratios had the lowest fibrousness scores, while samples with higher SPI contents had the highest fibrousness ratings. Samples with higher SPI and INL contents also presented the highest and lowest scores respectively for mouth coating. Stading and Hermansson (1990) found that 10-12% solutions of β-lactoglobulin preheated to 90-95 °C formed fine-stranded gels

TABLE 2. MIXED ANALYSIS OF VARIANCE ON THE SENSORY ATTRIBUTES RATED BY THE TRAINED PANEL (11 SPI:INL RATIOS, FPP AND F/TPP SAMPLES, FOUR ASSESSORS). ***F*** **AND** ***P*** **VALUES**

Descriptor	SPI:INL ratio (S) (df =10)		Treatment (T) (df =1)		Assessor (A) (df =3)		S × T (df =10)		T × A (df =3)		S × A (df =30)	
	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*
Visual graininess	104.89	0.000	254.86	0.000	0.47	0.708	57.64	0.000	1.44	0.284	1.48	0.252
Creaminess	27.03	0.000	9.05	0.006	1.03	0.414	3.39	0.020	0.13	0.938	1.08	0.504
Moisture	59.07	0.000	198.30	0.000	2.68	0.090	32.11	0.000	0.44	0.727	0.93	0.584
Consistency	51.24	0.000	837.29	0.000	2.77	0.093	11.72	0.000	0.90	0.472	0.54	0.908
Fibrousness	65.44	0.000	42.60	0.000	7.59	0.003	24.37	0.000	1.05	0.400	1.54	0.202
Mouth coating	42.99	0.000	97.50	0.000	0.71	0.569	4.92	0.002	3.45	0.057	1.51	0.246

F **values calculated considering main effects and interactions as fixed parameters.**
SPI, soy protein isolate; INL, inulin; FPP, fresh potato puree; F/TPP, potato puree subjected to a freeze/thaw cycle.

with flexible or rigid strands at low and high pH respectively. Surely, the presence of such SPI threads provoked an increase in intensity of fibrousness and mouth coating detected in the samples with higher SPI contents.

In turn, F/TPP samples with higher SPI contents were also more negatively affected by a freeze/thaw cycle and registered a significant increase in surface graininess as compared to their FPP counterparts (Table 3). Hashizume *et al*. (1971) reported that soybean proteins, when frozen in a solution, associate by intermolecular S-S bonds and become partly insoluble after thawing because they are closer to each other due to the more highly concentrated solution produced by the partially frozen water. It is thought that these changes might lead to a pronounced increase in visual graininess and a more significant decrease in creaminess in the frozen samples with higher SPI concentrations when compared with their FPP counterparts. Conversely, when higher amounts of INL were added to F/TPP samples, they had a significantly lower grainy appearance and higher creaminess scores than those with added SPI at the higher concentrations. This result is in accordance with that observed previously in low-fat and whole milk set yoghurt (Guggisberg *et al*. 2009). The authors reported that with rising INL concentration, perception of the creaminess increases as well. When F/TPP samples with a higher added INL content were thawed by microwave, the water accumulated in INL crystallites probably tended to diffuse uniformly within the matrix, giving rise to a homogeneous structure due to readsorption of the water by the amylose. It is hypothesized that the presence of INL reduces starch retrogradation and may be effective in the melting of retrograded starch during thawing.

Finally, the incorporation of both SPI and INL ingredients, either alone or blended, significantly decreased the perceived moisture in the F/TPP samples as compared to their FPP counterparts, except in the samples with an added 6:1.5 ratio, which was also accompanied by a significant rise in consistency. This was due to intracellular water being drawn out osmotically when the product was thawed because of the freezing-induced concentration of the cell mass (Fernández *et al*. 2008). As a consequence, the perceived fibrousness and mouth coating were also mostly higher in the F/TPP samples than in their FPP counterparts.

Sensory Properties Evaluated by the Untrained Panel

Main Effects and Interactions as Fixed Parameters. The three-way mixed-model ANOVA indicated a significant ($P < 0.05$) SPI:INL ratio and assessor main effects for all the descriptors and the OA (Table 4). In these cases, it is important to know whether assessor variability may influence the estimation of SPI:INL ratio differences. The significance or not, of the effect of S × A interaction can provide information on this point. The effect of this interaction was significant for all the descriptors, indicating a certain lack of concordance within the panel. A part of the S × A interaction is due to scale use, but the remaining part can be due to other individual differences such as sensitivity, motivation and culture (Carlucci and Monteleone 2001). In turn, replicate effects were also significant for all the descriptors, except for moisture, and the OA, confirming that members of an untrained panel give big variation in their analytical evaluations.

TABLE 3. MEAN VALUES OF DESCRIPTOR SCORES RATED BY THE TRAINED PANEL AND CORRESPONDING FISHER'S LEAST SIGNIFICANT DIFFERENCE FOR THE 22 FPP AND F/TPP SAMPLES

SPI:INL ratio	Treatment	Visual graininess	Creaminess	Moisture	Consistency	Fibrousness	Mouth coating
0:0	FPP	$1.55 \pm 0.26_{GH}$	$8.53 \pm 0.36*_{AB}$	$1.85 \pm 0.24_{F}$	$7.30 \pm 0.36*_{A}$	$1.27 \pm 0.09*_{H}$	$4.07 \pm 0.36*_{C}$
	F/TPP	$1.70 \pm 0.22_{e}$	$7.73 \pm 0.15_{c}$	$1.80 \pm 0.23_{e}$	$8.27 \pm 0.38_{a}$	$1.77 \pm 0.12_{ghij}$	$4.75 \pm 0.26_{cde}$
0:6	FPP	$1.57 \pm 0.30_{FGH}$	$8.80 \pm 0.11_{A}$	$6.32 \pm 0.22*_{A}$	$5.45 \pm 0.53*_{C}$	$1.42 \pm 0.25_{FGH}$	$2.80 \pm 0.22*_{D}$
	F/TPP	$1.30 \pm 0.18_{e}$	$8.88 \pm 0.13_{a}$	$4.80 \pm 0.36_{b}$	$6.75 \pm 0.24_{bcdefg}$	$1.30 \pm 0.08_{k}$	$4.40 \pm 0.37_{cde}$
1.5:4.5	FPP	$1.92 \pm 0.17_{DEF}$	$8.67 \pm 0.17_{A}$	$5.60 \pm 0.43*_{CD}$	$4.17 \pm 0.33*_{EFGH}$	$1.90 \pm 0.22*_{DE}$	$3.32 \pm 0.36*_{D}$
	F/TPP	$1.72 \pm 0.25_{e}$	$8.18 \pm 0.65_{abc}$	$4.82 \pm 0.31_{b}$	$6.25 \pm 0.53_{gh}$	$1.42 \pm 0.12_{ijk}$	$4.05 \pm 0.46_{def}$
3:3	FPP	$1.50 \pm 0.26_{H}$	$8.13 \pm 0.36*_{BC}$	$6.10 \pm 0.18*_{ABC}$	$4.57 \pm 0.31*_{DEF}$	$1.40 \pm 0.22_{GH}$	$3.15 \pm 0.31*_{D}$
	F/TPP	$1.40 \pm 0.18_{e}$	$8.65 \pm 0.19_{ab}$	$3.12 \pm 0.22_{d}$	$8.47 \pm 0.40_{a}$	$1.40 \pm 0.22_{jk}$	$5.12 \pm 0.58_{bc}$
4.5:1.5	FPP	$2.62 \pm 0.15*_{A}$	$7.30 \pm 0.55*_{DE}$	$6.15 \pm 0.46*_{AB}$	$3.52 \pm 0.41*_{IJ}$	$2.62 \pm 0.33_{A}$	$4.90 \pm 0.68*_{B}$
	F/TPP	$4.07 \pm 0.29_{c}$	$6.65 \pm 0.80_{de}$	$4.10 \pm 0.48_{c}$	$6.27 \pm 0.41_{fgh}$	$2.95 \pm 0.26_{cd}$	$5.85 \pm 0.84_{ab}$
6:0	FPP	$1.95 \pm 0.13*_{CDE}$	$6.78 \pm 0.31_{E}$	$5.97 \pm 0.58*_{ABCD}$	$3.87 \pm 0.46*_{GHIJ}$	$2.20 \pm 0.36_{BCD}$	$5.97 \pm 0.33_{A}$
	F/TPP	$2.82 \pm 0.38_{d}$	$6.58 \pm 0.50_{de}$	$4.20 \pm 0.29_{c}$	$5.85 \pm 0.24_{h}$	$2.30 \pm 0.45_{ef}$	$5.75 \pm 0.76_{ab}$
1.5:6	FPP	$1.60 \pm 0.24_{EFGH}$	$8.63 \pm 0.17_{AB}$	$4.62 \pm 0.26*_{E}$	$5.67 \pm 0.33*_{BC}$	$1.55 \pm 0.26_{EFGH}$	$3.07 \pm 0.99_{D}$
	F/TPP	$1.77 \pm 0.17_{e}$	$8.23 \pm 0.48_{abc}$	$5.52 \pm 0.41_{a}$	$8.52 \pm 0.46_{a}$	$1.55 \pm 0.17_{hijk}$	$3.42 \pm 0.42_{f}$
3:4.5	FPP	$2.10 \pm 0.22*_{BCD}$	$7.65 \pm 0.21_{CD}$	$5.75 \pm 0.35_{BCD}$	$3.85 \pm 0.13*_{HIJ}$	$2.17 \pm 0.22_{CD}$	$3.30 \pm 0.45*_{D}$
	F/TPP	$2.70 \pm 0.22_{d}$	$7.98 \pm 0.42_{bc}$	$4.00 \pm 0.41*_{c}$	$6.60 \pm 0.45_{cdefg}$	$2.15 \pm 0.21_{fg}$	$4.00 \pm 0.57_{ef}$
4.5:3	FPP	$2.25 \pm 0.26*_{BCD}$	$6.93 \pm 0.30_{E}$	$6.00 \pm 0.28_{ABCD}$	$4.17 \pm 0.31*_{FGH}$	$2.37 \pm 0.30_{ABC}$	$5.02 \pm 0.26*_{B}$
	F/TPP	$2.95 \pm 0.29_{d}$	$6.98 \pm 0.74_{d}$	$4.27 \pm 0.48_{c}$	$6.92 \pm 0.09_{bcd}$	$2.60 \pm 0.29_{de}$	$5.90 \pm 0.34_{a}$
6:1.5	FPP	$2.22 \pm 0.33*_{BCD}$	$7.23 \pm 0.51*_{DE}$	$5.52 \pm 0.38_{D}$	$3.47 \pm 0.29*_{J}$	$2.30 \pm 0.18*_{ABC}$	$5.20 \pm 0.35*_{B}$
	F/TPP	$5.12 \pm 0.55_{b}$	$6.60 \pm 0.47_{de}$	$5.35 \pm 0.41_{a}$	$6.52 \pm 0.45_{defg}$	$3.57 \pm 0.43_{b}$	$6.27 \pm 0.41_{a}$
6:6	FPP	$2.40 \pm 0.34*_{BC}$	$7.03 \pm 0.62*_{E}$	$5.97 \pm 0.25*_{ABCD}$	$2.77 \pm 0.22*_{K}$	$2.35 \pm 0.21*_{ABC}$	$4.90 \pm 0.41*_{B}$
	F/TPP	$6.92 \pm 0.74_{a}$	$5.98 \pm 0.41_{e}$	$5.15 \pm 0.26_{ab}$	$6.30 \pm 0.48_{efgh}$	$4.15 \pm 0.48_{a}$	$6.12 \pm 0.58_{a}$

Attributes evaluated on 8 cm descriptive linear scales labelled at each anchor: (left anchor: 1 = "not detectable"; right anchor: 9 =”extremely intense”).

$_{A\text{-}K}$ for each descriptor and for the FPP samples mean values without the same letter are significantly different (*P* < 0.05).

$_{a\text{-}k}$ for each descriptor and for the F/TPP samples mean values without the same letter are significantly different (*P* < 0.05).

***For each descriptor and for the same SPI:INL ratio mean values between FPP sample and its F/TPP counterpart are significantly different (*P* < 0.05).**

SPI, soy protein isolate; INL, inulin; FPP, fresh potato puree; F/TPP, potato puree subjected to a freeze/thaw cycle.

TABLE 4. MIXED ANALYSES OF VARIANCE ON THE SENSORY ATTRIBUTES RATED BY THE UNTRAINED PANEL (SIX SPI:INL RATIOS, 27 ASSESSORS, THREE REPLICATES). *F* AND *P* VALUES

Descriptor	SPI:INL ratio (S)‡ (df =5)		Assessor (A)‡ (df =26)		Replicate (R)‡ (df =2)		S × A‡ (df =130)		A × R‡ (df =52)		S × R‡ (df =10)		SPI:INL ratio (S)† (df =5)	
	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*	F *value*	P *value*
Visual graininess	623.71	0.000	958.30	0.000	46.22	0.000	171.28	0.000	1.38	0.231	3.28	0.001	15.31	0.000
Creaminess	104.98	0.000	435.85	0.000	20.59	0.000	147.17	0.000	1.15	0.386	1.13	0.343	8.71	0.000
Moisture	8.22	0.002	244.00	0.000	1.77	0.217	135.83	0.000	1.38	0.235	1.19	0.305	5.94	0.002
Consistency	503.37	0.000	415.76	0.000	31.77	0.000	88.59	0.000	1.09	0.442	0.90	0.529	34.17	0.000
Fibrousness	1,017.84	0.000	1,377.50	0.000	40.38	0.000	202.52	0.000	1.40	0.228	1.20	0.303	34.47	0.000
Mouth coating	71.57	0.000	366.74	0.000	23.95	0.000	119.01	0.000	1.19	0.351	1.98	0.038	4.88	0.000
OA	492.44	0.000	362.62	0.000	44.65	0.000	120.39	0.000	0.97	0.558	1.07	0.393	25.34	0.000

† *F values* recalculated considering S as fixed parameter and A effect and S × A interaction as random variables in the model.

‡ *F values* calculated considering main effects and interactions as fixed parameters.

SPI, soy protein isolate; INL, inulin; OA, overall acceptability.

Assessors and Interaction as Random Effects. In spite of the relevance of the S × A interaction, the main SPI:INL ratio effect for all attributes and OA remained significant when the ANOVA model was applied considering assessor and interaction as random effects (Table 4). This means that when the influence of individual differences between assessors was eliminated, all textural attributes and overall acceptability differed among F/TPP samples. This result also indicates that the untrained panel did not create enough variance to obscure differences between samples with different added SPI:INL ratios. However, the S effect is much less significant for the model when assessor and interaction are considered as random variables, confirming that the distinction could have wide-ranging consequences (Næs and Langsrud 1998).

Effect of the SPI:INL Ratio in the F/TPP Samples. Once the mean values of the descriptors and the OA of samples and the significant differences between them (Table 5) had been established, the sensory differences were analyzed relating to SPI and INL content. Grainy appearance scores were higher for the control, for the samples with SPI added alone and unexpectedly for those with an added 1.5:6 ratio. Samples with added 0:6, 3:3 and 1.5:6 ratios registered the highest scores for creaminess. In turn, the moisture scores of samples with added INL alone and with a 4.5:3 ratio were significantly higher than that of the 0:0 control. The perceived consistency decreased significantly with the addition of INL alone but increased considerably with the addition of only SPI. Fibrousness of samples with added SPI alone did not differ appreciably from that of the 0:0 control, while mouth coating remained within very narrow margins of variation. Note that although differences between samples were significant for the six attributes, scores in Table 5 show relatively little variation per attribute between samples, clearly indicating that the level of the training and the experience affected perception (Table 3). Additionally, samples with higher INL contents (0:6 and 1.5:6 ratios) had higher OA scores. In these samples, untrained panelists

TABLE 5. MEAN VALUES OF DESCRIPTOR AND OA SCORES RATED BY THE UNTRAINED PANEL AND CORRESPONDING FISHER'S LEAST SIGNIFICANT DIFFERENCE FOR THE SIX SELECTED F/TPP SAMPLES

SPI:INL ratio	Visual graininess	Creaminess	Moisture	Consistency	Fibrousness	Mouth coating	OA
0:0	$4.51 \pm 2.33_{a}$	$5.98 \pm 1.62_{b}$	$4.98 \pm 2.03_{bc}$	$5.29 \pm 2.00_{b}$	$5.38 \pm 2.24_{a}$	$5.47 \pm 1.92_{bc}$	$5.72 \pm 1.68_{c}$
0:6	$3.43 \pm 1.70_{b}$	$6.46 \pm 1.67_{a}$	$6.20 \pm 1.85_{a}$	$4.15 \pm 1.60_{d}$	$3.43 \pm 1.55_{c}$	$5.53 \pm 1.86_{c}$	$6.27 \pm 1.81_{b}$
3:3	$3.09 \pm 1.55_{b}$	$6.35 \pm 1.93_{a}$	$5.34 \pm 2.00_{bc}$	$4.67 \pm 2.02_{c}$	$4.49 \pm 2.43_{b}$	$5.69 \pm 1.98_{ab}$	$5.28 \pm 1.93_{d}$
6:0	$4.59 \pm 2.10_{a}$	$5.70 \pm 1.65_{b}$	$5.00 \pm 1.82_{c}$	$5.93 \pm 1.31_{a}$	$5.30 \pm 2.19_{a}$	$6.06 \pm 1.70_{a}$	$5.09 \pm 1.16_{d}$
1.5:6	$4.20 \pm 1.77_{a}$	$6.34 \pm 1.28_{a}$	$6.44 \pm 4.84_{ab}$	$4.67 \pm 1.51_{c}$	$3.58 \pm 1.62_{c}$	$6.02 \pm 1.67_{bc}$	$6.69 \pm 1.29_{a}$
4.5:3	$3.72 \pm 2.08_{b}$	$6.15 \pm 1.81_{b}$	$5.96 \pm 1.60_{a}$	$4.51 \pm 1.56_{c}$	$3.64 \pm 1.62_{c}$	$5.60 \pm 1.50_{b}$	$5.46 \pm 1.63_{d}$

Attributes evaluated on 8 cm descriptive linear scales labeled at each anchor: (left anchor: 1 = "not detectable"; right anchor: 9 = "extremely intense").
$_{abcd}$For each descriptor and OA mean values without the same letter are significantly different (*P* < 0.05).
SPI, soy protein isolate; INL, inulin; OA, overall acceptability; F/TPP, potato puree subjected to a freeze/thaw cycle.

mainly associated OA with creaminess, smoothness, softness, and pleasantness. De Wijk *et al*. (2003) stated that creaminess in custard desserts is related to a combination of sensations of mouthfeel (thickness and fattiness), after-feel (fatty coating and absence of fibrousness) and flavor/taste sensations (creamy and fatty flavors, an absence of bitterness). In contrast, presence of SPI at quite high concentrations (>1.5%) decreased the OA of the product compared with the control, mainly because assessors found that SPI gave the PPs an unfamiliar taste and odor.

Correlations Between Descriptors Rated by Untrained and Trained Panels

A graphical representation of the sensory profile for the six F/TPP samples rated by both trained and untrained panels is given in Fig. 1. In the samples rated by the trained panel (Fig. 1A), creaminess and consistency are the dominant descriptors in terms of the perceived intensity. Visual graininess and fibrousness were minimally perceived, while moisture and mouth coating were perceived to be moderately intense. In the samples rated by the untrained panel (Fig. 1B), all the descriptors were perceived as moderately intense. It is therefore clear that through experience, the trained assessors had developed a broader perceptual range of textures which is in agreement with Cardello *et al*. (1985).

Mean scores for the trained panel were regressed against mean scores for the untrained panel for each descriptor. Correlation coefficients were not statistically significant for five of the six descriptors, indicating a lack of linearity between scores made by the two panels (data not shown). Creaminess was the only significantly correlated descriptor (r = 0.88). For this multimodal sensation, the slope of the regression equation was greater than 1.0 (2.84), confirming that a greater range of perceptual differences were perceived in the stimulus series by the trained panel (Cardello *et al*. 1985). Differences in the sensory scores assigned by trained and untrained assessors for the rest of the descriptors could be ascribed to (1) those specific to potato puree, since the trained panel had been evaluating PP samples for 8 years, (2) those specific to the use of an 8 cm descriptive linear scale, or (3) simply due to differences between the techniques used by the trained and untrained assessors to evaluate these descriptors. Definitely, a common understanding of the meaning of different texture descriptors among the members of a sensory panel is needed to obtain reproducible results.

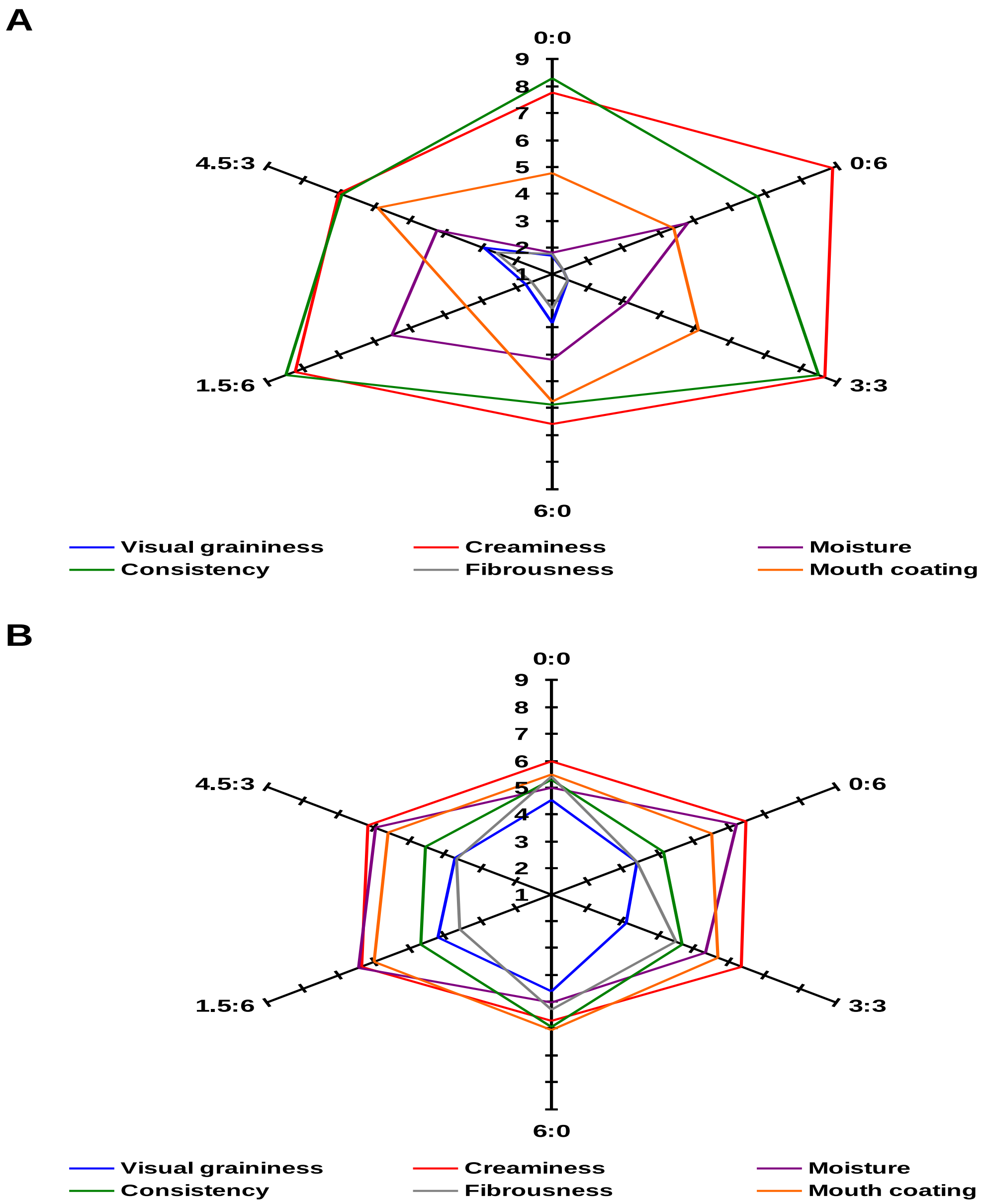

FIG. 1. COMPARISON OF RATINGS FOR DESCRIPTORS OF FROZEN/THAWED POTATO PUREE WITH ADDED SOY PROTEIN ISOLATE (SPI) AND INULIN BLENDS WITH SIX SELECTED SPI : INL RATIOS.
(A) Rated by the trained panel and (B) rated by the untrained panel.

Rheological Behavior

Characterization of the PP Samples. Plots of shear stress vs. shear rate for both FPP and F/TPP samples with added 0:0, 0:6, 3:3, 6:0, 1.5:6 and 4.5:3 ratios revealed a non-Newtonian flow behavior and exhibited typical pseudoplastic behavior and yield stress (Fig. 2A,B). The flow curves were similar in all the other products. This type of behavior is in accordance with that observed previously in PP (Fernández *et al*. 2008). Most of FPP and F/TPP samples with added SPI/INL blends presented lower resistance to flow than the controls, although the performance of a freeze/thaw cycle decreased the differences between the rheological behavior of the 0:0 control and that of the samples with added 3:3 and 1.5:6 ratios (Fig. 2B). F/TPP samples exhibited greater shear stress than their FPP counterparts.

Effect of the SPI:INL Ratio and a Freeze/Thaw Cycle on the Rheological Properties. The two-way mixed-model ANOVA indicated a significant ($P < 0.01$) S and T main effects for all the rheological properties and indices (Table 6). Furthermore, S × T interactions were significant for K, $\eta_{app,50}$ and σ_{oral} values. In spite of this, samples with added SPI:INL ratios had similar pseudoplasticity (n) to the 0:0 control, although a freeze/thaw cycle increased pseudoplasticity of the samples.

Generally speaking, the addition of SPI/INL blends reduced the consistency index, the apparent viscosity at 50/s and the instrumental index of oral consistency with respect to the 0:0 control. At a fixed INL content, the K, $\eta_{app,50}$ and σ_{oral} values decreased with increasing SPI concentration from 1.5 to 6%, evidence of a decreased number of intermolecular cross-links resulting in a weaker matrix. This behavior is typical of gels filled with deformable particles (Jampen *et al*. 2001). According to the latter authors, in gels containing deformable particles, the linear decrease in storage modulus in line with increasing volume fractions is due to particle compliance under stress or to particle separation from the matrix, thereby

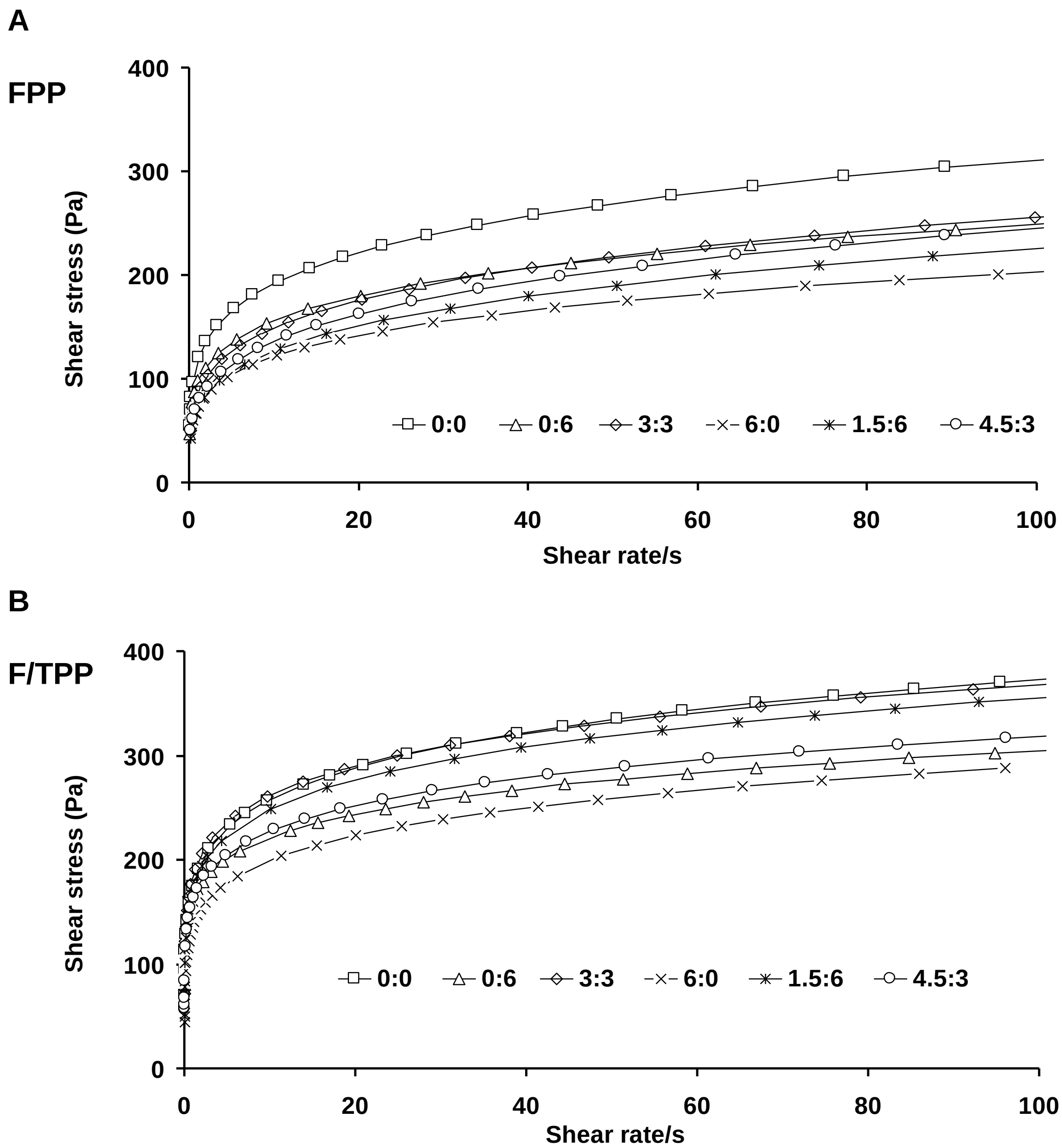

FIG. 2. STRESS SWEEP CURVES OF POTATO PUREE WITH ADDED SOY PROTEIN ISOLATE (SPI) AND INULIN (INL) BLENDS WITH SIX SELECTED SPI: INL RATIOS
(A) Fresh potato puree (FPP) and (B) frozen/thawed potato puree (F/TPP).

causing gel weakening. At a fixed total concentration of 6%, the lowest *K*, $\eta_{app,50}$ and σ_{oral} values were recorded in the samples with added SPI alone (6:0 ratio). The *K*, $\eta_{app,50}$ and σ_{oral} values were significantly higher in the samples with only added INL than in those with added SPI alone, visibly indicating that the addition of INL alone caused rather less softening than adding SPI alone. As stated previously by Kaur and Gupta (2002), long-chain INL can form microcrystals. Thus, the smaller decrease observed in the rheological parameters of samples with an added 0:6 ratio could be attributed to the starch exclusion effect, which would lead to the formation of aggregates containing INL crystals. These aggregates would retain a high amount of liquid phase and the volume fraction would increase (Bot *et al*. 2004). This would justify that supplementary addition of INL exhibited a significant ($P < 0.01$) strengthening effect on the samples with added SPI alone.

Furthermore, it can be observed that in all cases both consistency indices and apparent viscosity were significantly lower in the FPP samples than in the F/TPP ones due to an amylopectin retrogradation process. The appearance of a spongy, stratified and flaky texture as a result of freezing and thawing was also observed by Ferrero and Zaritzky (2000), but this study did not include sensory assessment of the samples. Mason (2009) stated that starch retrogradation causes syneresis and appearance changes such as graininess and opacity as well as texture changes, including loss of smoothness. In this study, XG (0.15% w/w) was added to PP samples in order to minimize amylose retrogradation, syneresis and rheological changes after freezing (Alvarez *et al*. 2009), but as already stated XG addition does not prevent ice recrystallization nor amylopectin retrogradation.

High bilateral correlations of 0.92 and 0.97 were found between the $\eta_{app,50}$ and *K* and between the $\eta_{app,50}$ and σ_{oral} respectively (Table 7), so only S × T interactions for *K* and σ_{oral} are shown in Fig. 3. The most remarkable effect was that the F/TPP samples with an added 3:3 ratio had notably higher *K* values than the 0:0 control (Fig. 3A), although there were no

TABLE 6. EFFECTS OF SPI:I RATIO AND A FREEZE/THAW CYCLE ON FLOW RHEOLOGICAL PROPERTIES AND INDICES OF PP WITH ADDED SPI/INL BLENDS

Source	n	K (Pa·s^n)	$\eta_{app,50}$ (Pa·s)	τ_{oral} (Pa)
Main effects:				
SPI:INL ratio (S)				
0:0	0.19_{abcd}	146.25_{a}	6.24_{a}	224.62_{a}
0:6	0.17_{cd}	125.01_{bcd}	4.79_{c}	184.07_{cd}
1.5:4.5	0.22_{a}	108.28_{efg}	4.93_{bc}	177.74_{d}
3:3	0.19_{abcd}	134.26_{ab}	5.36_{b}	202.39_{b}
4.5:1.5	0.21_{ab}	121.68_{bcd}	5.32_{b}	192.67_{bc}
6:0	0.20_{abc}	100.13_{g}	4.18_{d}	157.63_{e}
1.5:6	0.19_{abcd}	125.15_{bcd}	4.93_{bc}	189.81_{bcd}
3:4.5	0.21_{ab}	121.08_{cde}	5.20_{bc}	191.05_{bcd}
4.5:3	0.21_{ab}	114.14_{def}	4.96_{bc}	179.38_{cd}
6:1.5	0.17_{d}	128.71_{bc}	4.78_{c}	183.73_{cd}
6:6	0.18_{bcd}	104.23_{fg}	3.87_{d}	156.89_{e}
P value	0.003	0.000	0.000	0.000
LSD (99%)	*0.03*	*12.93*	*0.51*	*13.68*
Freeze/thaw cycle (T)				
FPP	0.23_{a}	81.15_{b}	4.03_{b}	141.83_{b}
F/TPP	0.15_{b}	160.47_{a}	5.89_{a}	229.08_{a}
P value	0.000	0.000	0.000	0.000
LSD (99%)	*0.01*	*5.51*	*0.22*	*5.83*
Interaction				
S × T	0.103	0.000	0.001	0.000

$_{a-e}$ For each rheological property or index and effect studied mean values without the same letter are significantly different (*P* < 0.01). SPI, soy protein isolate; INL, inulin; FPP, fresh potato puree; F/TPP, potato puree subjected to a freeze/thaw cycle; PP, potato puree; LSD, least significant difference.

significant differences in the σ_{oral} values of the F/TPP samples with added 0:0 and 3:3 ratios (Fig. 3B). Therefore, the presence of both ingredients at certain ratios was found to enhance the consistency of F/TPP samples when compared to those with either SPI or INL added alone. Tseng *et al*. (2009) reported that the addition of 5% (w/v) long-chain INL enhanced the gelation of SPI and the 7S (β-conglycinin)/11S (glycinin) mixture, which was evident from the increases in gel storage modulus by up to 13.6 and 10.1%, respectively.

Correlations ranging from -0.75 to 0.89 were found between the oral consistency perceived by the trained panel and the rheological properties and derived indices (Table 7). Therefore, differences in the rheological behavior of samples explain quite well the above sensory variations perceived with respect to sensory consistency. However, the other five sensory texture attributes cannot be related to a single physical property of the PP in a simple way.

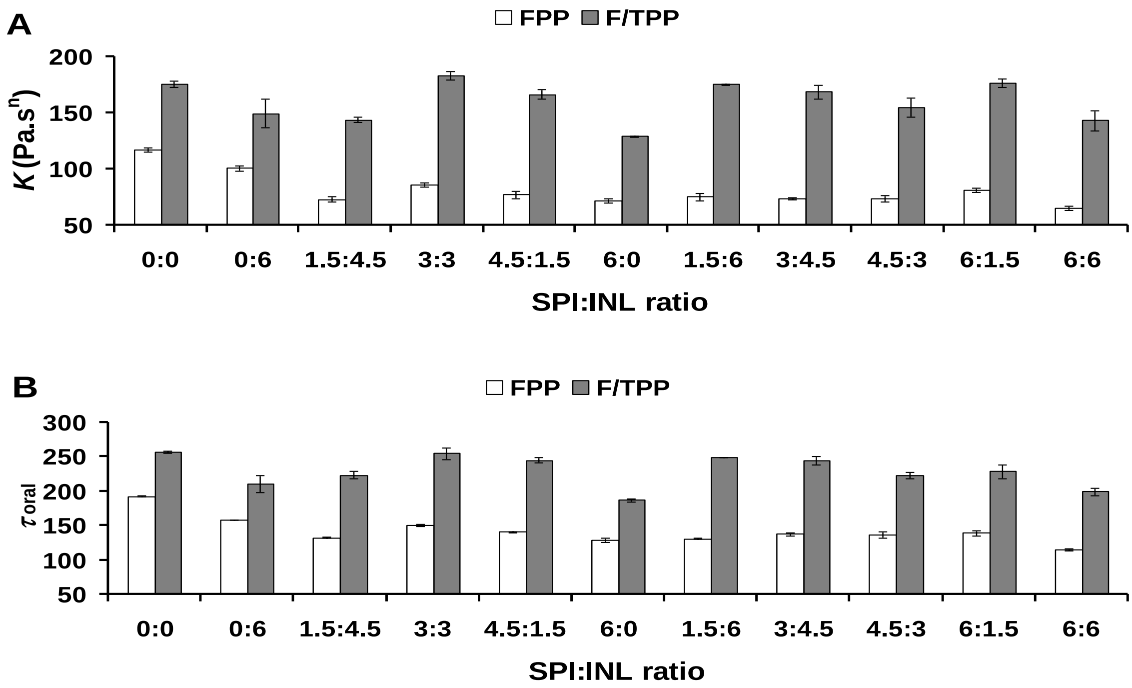

FIG. 3. RHEOLOGICAL BEHAVIOR OF FPP AND F/TPP WITH ADDED SPI AND INL BLENDS WITH ELEVEN DIFFERENT SPI:INL

(A) Consistency index (*K*) and (B) Kokini oral shear stress (σ_{oral}). FPP, fresh potato puree; F/TPP, frozen/thawed potato puree; SPI, soy protein isolate; INL, inulin.

TABLE 7. PEARSON CORRELATION COEFFICIENTS BETWEEN RHEOLOGICAL PROPERTIES, INDICES AND ORAL CONSISTENCY RATED BY THE TRAINED PANEL FOR PP SAMPLES WITH ADDED SPI/INL BLENDS

	n	K	$\eta_{app,50}$	σ_{oral}	Oral consistency
N	1	-0.90	-0.69	-0.82	-0.75
K	-	1	0.92	0.98	0.88
$\eta_{app,50}$	-	-	1	0.97	0.85
σ_{oral}	-	-	-	1	0.89
Oral consistency	-	-	-	-	1

SPI, soy protein isolate; INL, inulin; PP, potato puree.

Microstructure Examination

Fig. 4 shows the morphological differences between the six selected F/TPP samples rated by both trained and untrained panels. The 0:0 control (Fig. 4A) consists mainly of a continuous phase (amylose/amylopectin matrix) due to the disruption and complete solubilization of the starch granules caused by cooking. It is clear that in the 0:6 ratio (Fig. 4B), INL crystallites were dispersed throughout the amylose/amylopectin matrix, forming a strong gel with characteristics of a one-phase system. Using optical microscopy, Zimeri and Kokini (2003) observed INL crystals immersed in the continuous phase in samples with 5% long-chain INL. Analogously, Bayarri *et al*. (2011), by means of SEM, observed the presence of INL aggregates embedded in the continuous matrix of starch-dairy systems. Even in this study, the probable loss of water due to a freeze/thaw cycle provoked the formation of closely packed INL crystallites in the INL-rich phase. This structure is associated with a significant increase in creaminess and moisture scores rated by both panels, and characterized by either lower sensory or instrumental consistencies in comparison with the F/TPP 0:0 control (Tables 3 and 5; Fig. 3). A clear relationship was observed between the microstructure of whey protein isolate/gellan gum gels, serum release and the grading of the sensory watery characteristic (van Vliet *et al*. 2009). The slight thinness found in 0:6 ratio should not be considered of major importance as the quality of the product was improved. Note that the untrained panel preferred the PPs enriched with the highest INL concentration used, this smoothness and decreased sensation of graininess being ascribed to increased INL. The decreased oral graininess is the result of the lubricating and coating properties of INL crystals, which clearly masked the fibrousness detected in the 0:0 control.

In the case of samples with an added 3:3 ratio (Fig. 4C), it is not possible to appreciate any gel SPI structure (probably because no gelation occurred). In addition, the INL did not form a continuous phase, since its lower concentration reduced the density of these particles in the product. It is possible to appreciate spherical and obloid-shaped INL crystallites throughout the sample but with fewer interconnections between them compared with the added 0:6 ratio (Fig. 4B). This fact might have led to reduced lubrication and a drier sensation, as reflected by an increase in both the consistency index (Fig. 3A) and the perceived consistency accompanied by a decrease in the wet feeling in the mouth (Table 3).

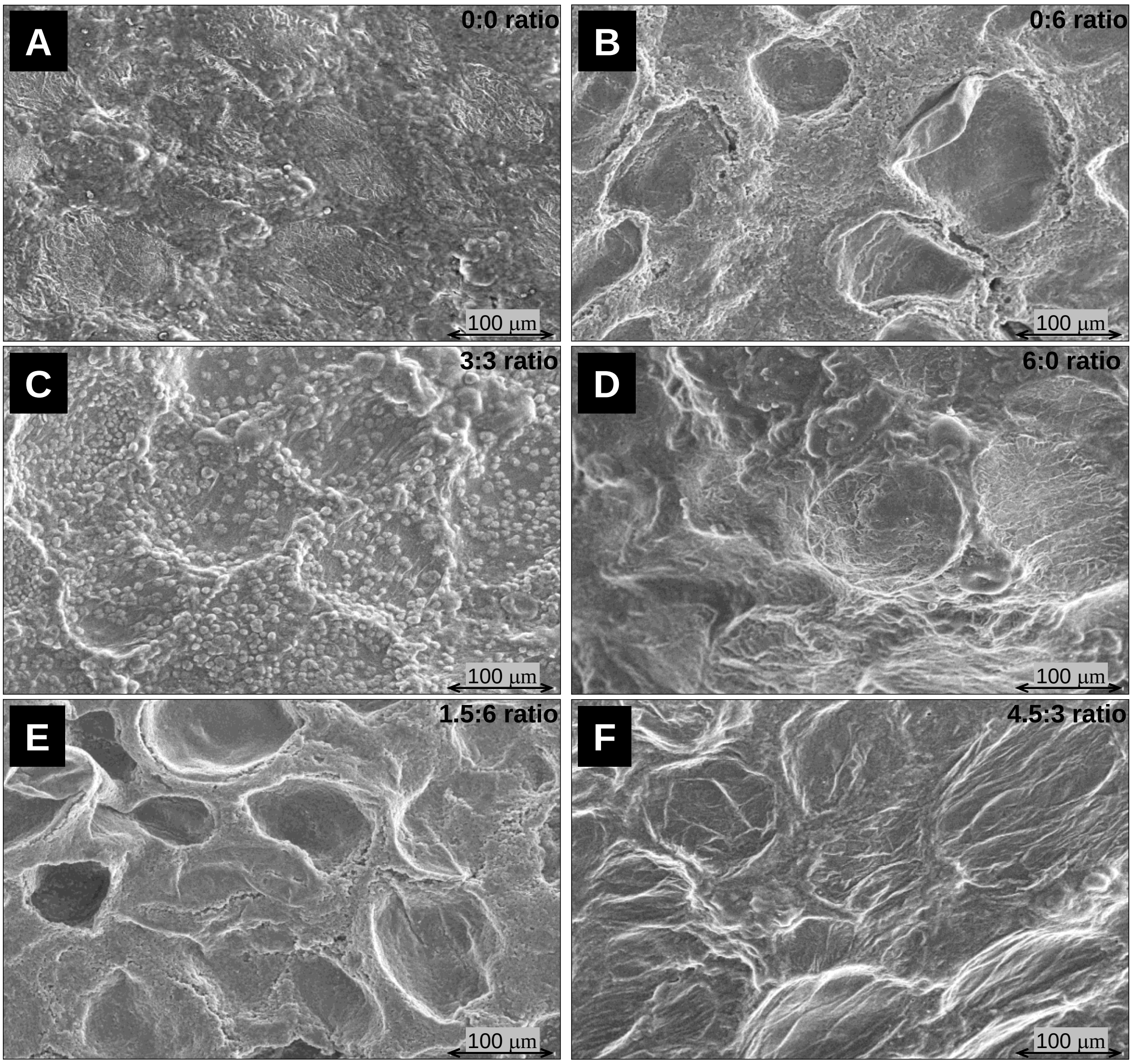

FIG. 4. MICROGRAPHS OF FROZEN/THAWED POTATO PUREE WITH ADDED SOY PROTEIN ISOLATE (SPI) AND INULIN (INL) BLENDS WITH SIX SELECTED SPI:INL RATIOS

(A) 0:0 ratio. (B) 0:6 ratio. (C) 3:3 ratio. (D) 6:0 ratio. (E) 1.5:6 ratio. (F) 4.5:3 ratio. Magnification was 200 (bar = 100 μm).

On adding SPI alone at 6%, proteins formed a network composed predominantly of filamentous SPI aggregates (Fig. 4D), although some particulate clusters of aggregates can also be seen. For globular proteins, generally two different types of gel networks can be distinguished, fine-stranded and coarse networks, but intermediate structures have also been reported (Lakemond *et al*. 2003). This coarse-stranded SPI gel was characterized by a significant decrease in the rheological properties and consistency perceived by the trained panel. The influence of particle-matrix interactions was studied by van Vliet (1988) who found that a linear decrease in gel strength with an increase in volume fraction only occurred with non-interacting gel materials. As stress is applied to the system, small amounts of water may be released from the SPI strands, thus forming an aqueous boundary layer around them and reducing any interactions with the amylose/amylopectin matrix. Addition of SPI alone gave rise to a less creamy, rougher product with more mouth coating, which could also be explained by the presence of these filamentous SPI aggregates.

The appearance of samples with an added 1.5:6 ratio (Fig. 4E) was quite similar to that of samples with added INL alone (Fig. 4B), forming a continuous INL network without appreciable protein inclusions. In contrast, the appearance of samples with an added 4.5:3 ratio was quite unlike that of samples with an added ratio of 3:3. In samples with 4.5% added SPI and 3% added INL (Fig. 4F), SPI again formed a filamentous network without distinguishable INL crystals which would be preferentially excluded from the protein surfaces. Thus, SPI at 4.5% supports the INL structure by building up a second coarse-stranded network. There were also some differences between samples with added 6:0 and 4.5:3 ratios. When 4.5% SPI was blended with 3% INL (Fig. 4F), the SPI gel structure had thicker, more shrunken strands than with added SPI alone (Fig. 4D). In spite of staying hidden, INL crystallites significantly strengthened the F/TPP samples with SPI gel alone (Fig. 3). The presence of INL must have a synergistic effect on SPI gelation, and this effect may depend on SPI concentration, the SPI:INL ratio, and possibly solvent properties (e.g., water activity). It is well known that freezing reduces water activity due to ice formation and the high concentrations of solutes in unfrozen water. When the concentration of SPI, was high, the addition of INL probably caused more a_w reduction, exerted stronger hydrogen bonding with water, and/or produced greater physical interactions (e.g., entanglements) with SPI molecules. Such reactions, combined with the excluded volume effect, would lead to enhanced protein-protein interactions as manifested by the increase in rheological properties. According to Tseng *et al*. (2009), the excluded volume effect is likely the major force driving soy globulins into a more stable state in the presence of this neutral carbohydrate.

CONCLUSION

Despite an untrained panel being able to distinguish between PP samples with different added SPI:INL ratios, only a good linear correlation was observed between trained and untrained evaluations for creaminess. Perceived consistency rated by the trained panel was linked to flow rheological indices which show that there is no interaction between the amylose/amylopectin matrix and the dispersed particles. Presence of SPI strands was a dominant factor in texture perception, regarding mouth feel geometric attributes (visual graininess and fibrousness) and after feel attribute (mouth coating), while INL crystallites were the main feature influencing creaminess. The addition of small amounts of SPI (1.5%) and INL at >3% increased the intensity of perceived creaminess. SPI-water interactions would appear to be weaker than those between INL and water, and the more fluid-like behavior observed in samples with added SPI at concentrations ≥ 4.5% may be attributable to water release from the SPI gel in the discontinuous phase. Microstructural characteristics are evidently needed to understand the non-mechanical part of the perceived texture in PPs with these added functional ingredients.

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SENSORY DESCRIPTION OF POTATO PUREE ENRICHED WITH INDIVIDUAL FUNCTIONAL INGREDIENTS AND THEIR BLENDS.

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ABSTRACT

This study compares trained, semi-trained and untrained sensory profiles for seven potato puree (PP) samples by using quantitative descriptive analysis (QDA), flash profiling (FP) and projective mapping (PM), respectively. Data analysis methods for QDA, FP and PM were principal component analysis, generalized Procrustes analysis and multiple factor analysis (MFA). For the three profiling techniques, hierarchical clustering analysis was applied to group PPs as per their sensory profiles. Assessors' consensus was analyzed through MFA and correlation coefficients. For each technique, MFA also allowed assessing correlations between sensory and instrumental variables. Results showed that both FP and PM methodologies were able to identify differences in sensory characteristics of PPs, providing very similar sensory maps. Nevertheless, higher correlations between sensory attributes evaluated by semi-trained and trained assessors were found, indicating that preferably FP should be used as a rapid choice to QDA in hot served PPs.

KEYWORDS

Extra virgin olive oil, flash profile, long-chain inulin, potato puree, projective mapping, quantitative descriptive analysis, soy protein isolate

PRACTICAL APPLICATIONS

But even with some restrictions, results of this study showed that with semi-trained and untrained panels, spatial configurations obtained by FP and PM were relevant to describe sensory profiles of PPs. Both rapid substitute methods presented a strong correlation with QDA (high regression vector coefficients), but FP task would be preferred over PM. However, one disadvantage of these techniques is that they do not allow obtaining average rating scores, and therefore an assessment of least significant differences via ANOVA can not be done. Therefore, it is important to highlight that both FM and PM methodologies might be particularly recommended when you cannot train a panel for a specific application, but preferably they should be considered complementary to trained assessors' data. Application of these consumer profiling techniques showed that there is a possibility of using inulin in combination with PPs to provide a highly nutritious product with improved consumers' acceptance.

INTRODUCTION

Descriptive analysis involves the detection (discrimination) and the description of both the qualitative and quantitative sensory aspects of a product by trained panels of judges (Meilgaard *et al.* 2007). Amongst the most widely used descriptive analysis is the quantitative descriptive analysis (QDA) (Stone *et al.* 1974). It is based on the principle of a panelist's ability to verbalize perceptions of a product in a reliable manner; panelists are screened and trained in attribute recognition and scaling, they use a common and agreed sensory language, and products are scored on repeated trials to obtain a complete quantitative description (ASTM 1992).

Sensory science has developed several new methodologies of sensory mapping and profiling alternative to conventional profiling as well as new statistical analysis, e.g., the free choice profiling (Williams and Langron 1984), the spectrum method (Meilgaard *et al.* 2007), and the ultra-flash profiling (Perrin *et al*. 2008). Between these recent methodologies are also flash profiling (FP) (Sieffermann 2000; 2002) and projective mapping (PM) (Pagès 2005), which are attractive because they do not demand a training stage and individual sessions are possible (Albert *et al*. 2011). FP is an original combination of free-choice terms selection in combination with ranking method based on simultaneous presentation of the whole product set (Dairou and Sieffermann 2002). Others main specificities of FP are to allow to judges the use of their own list of attributes (Delarue and Sieffermann 2004). PM, and its variant Napping, are profiling methods that were developed (Pagès 2005) in order to collect an Euclidean configuration for each assessor in a single sensory session. Samples simultaneously presented are positioned by each assessor on a tablecloth or a blank paper according to the differences/similarities (sensory distances) present between them in such a way that the smaller the distance separating two samples, the more similar they are (Perrin *et al*. 2008). The positioning criteria and their importance are chosen on an individual basis by each assessor, which makes PM a flexible and spontaneous procedure (Moussaoui and Varela 2010). The simultaneous processing of all these configurations provides a graphical display of the product in which two products are near if they were perceived similar by the whole panel of subjects (Pagès 2005).

Nevertheless, there are only few works comparing these techniques systematically in the same sample set, and where these three methods – QDA, FP and PM – have been compared simultaneously for foods that are served hot. Moussaoui and Varela (2010) explored the performance of FP and PM methods and their linkage to a QDA among target consumers of hot beverages. Following, Albert *et al*. (2011) used QDA, FP and PM to study their suitability on hot fish nuggets, and concluding that FP and PM could be used as quick alternatives to QDA in these products.

Potato purees (PPs) themselves make up a combined system of native potato starch, denatured milk protein, water and salt plus added cryoprotectants (kappa-carrageenan [κ-C] and xanthan gum [XG]) as the product is intended to be frozen (Alvarez *et al.* 2012). Variations in the composition of PPs by adding new ingredients would produce noticeable differences in the physical and sensory properties of the final product (Bayarri *et al*. 2011). For example, addition of extra virgin olive oil (EVOO) enhanced the PPs sensory quality reducing granularity, denseness, cohesiveness, adhesiveness and fibrousness, and increasing homogeneity, ease of swallowing and palate coating (Alvarez *et al*. 2011b). Addition of long-chain inulin (INL) gave rise to a low-fat semisolid dairy dessert with the same thickness intensity as the full-fat sample, though less creamy, rougher and with more mouth coating (Bayarri *et al*. 2011). In turn, assessors found that soy protein isolate (SPI) conferred excessive thickness and gave the PPs an unfamiliar taste and odor (Alvarez *et al*. 2012).

Previous sensory analyses showed that the preferred temperature for PP consumption was 55C (Alvarez *et al*. 2011b, 2012). Therefore, a problem for the assessment of these products is the preparation and heating processes and the necessity of serving the samples hot at homogeneous temperature for the whole panel in a sensory test. However, as both FP and PM are based in the comparison of the entire sample set at once, this requires a consistency in the samples received by each assessor, but it allows being slightly more relaxed in the handling of the samples within assessors (Albert *et al*. 2011). According to the latter authors, in QDA a variation in a couple of degrees in temperature could cause a significant change in texture ratings, which would ultimately change the final averages or the panel-performance-related parameters.

Taking the above into consideration, this study aimed to: (1) prove whether semi-trained and untrained panels are able to describe PPs and generate relevant attributes by two descriptive methods: FP and PM; (2) contrast the applicability of the two methods and to correlate the outcomes to a trained panel via QDA; and (3) ascertain correlations between textural attributes generated by the three panels and instrumental variables.

MATERIALS AND METHODS

Materials

The potatoes used were fresh tubers (cv Kennebec) from Aguilar de Campoo (Burgos, Spain) grown in 2011. EVOO (Carbonell, Sevilla, Spain) was chosen for addition to the PP. INL (Orafti HP, BENEO-Orafti, Tienen, Belgium) was a “long-chain” INL with a degree of polymerization, DP ≥ 23 and 99.5% purity (producer’s data). Readily dispersible SPI **(**PRO-FAM 646, ADM, Netherlands) was used without further purification. κ-C (GENULACTA carrageenan type LP-60) and XG (Keltrol F [E]) were donated by Premium Ingredients, S.L. (Girona, Spain). The amount of each ingredient, either alone or in blends, that could be added to the PP control was based in previous studies (Alvarez *et al*. 2011a,b, 2012). Codes samples and composition of the seven PPs studied are presented in Table 1. These seven PPs were selected in order to cover a wide texture space, with distinctive sensory properties. After preparation all samples were subjected to a freeze/thaw cycle.

TABLE 1. COMPOSITION* OF THE POTATO PUREE SAMPLES STUDIED WITH CODES USED FOR THEIR IDENTIFICATION

Sample code	EVOO (%)	INL (%)	SPI (%)
C	0	0	0
EVOO	3	0	0
INL	0	4.5	0
SPI	0	0	3
EVOO + INL	3	4.5	0
EVOO + SPI	3	0	3
INL + SPI	0	4.5	3

***Percentages of the total raw ingredients.**

C, control sample; EVOO, extra virgin olive oil; INL, inulin,; SPI, soy protein isolate.

Preparation of PP Samples

Tubers were manually washed, peeled and diced. The seven fresh PP samples were prepared in ~1,350-g batches from 790 g of potatoes, 300 mL of semi-skimmed in-bottle sterilized milk, 200 mL of water, 10 g of salt (NaCl) and 1.95 g each of two hydrocolloids, κ-C and XG (Premium Ingredients, S.L., Girona, Spain), using a TM 31 food processor (Vorwerk España, M.S.L., S.C., Madrid, Spain). When used, at this point, EVOO was added at 3% to the rest of the ingredients. This amount was removed from the initial water content (200 mL). Analogously, when used, INL which had been previously dissolved in the 300 mL of milk and 150 mL of water at 70C for 15 min agitating constantly with a magnetic stirrer was added at 4.5%. In all the cases, the ingredients were first cooked for 30 min at 90C (blade speed: 40 rpm) and any evaporated water was replaced gravimetrically. In terms of processing, there were serious difficulties in cooking SPI together the rest of the ingredients. For this reason, when used, at this point SPI that had previously been hydrated at a ratio of SPI to water of 1:5 was added at 3%. Water used to hydrate SPI was removed from the initial water content (200 mL). Next, in all the cases, all the ingredients were cooked at 90C for 5 min. The mash was ground for 40 s (1,200 rpm) and 20 s (2,600 rpm), and then homogenized through a stainless steel sieve (diameter: 1.5 mm). Then, the seven fresh PP samples were frozen and thawed.

Freeze/Thaw Cycle

PP samples were placed on flat-freezing and microwave thawing trays, and then frozen by forced convection with liquid nitrogen vapor in an Instron programmable chamber (model 3119-05, -70/+250C) at -60C until their thermal centers reached -24C. After freezing, the samples were packed in polyethylene plastic bags, sealed under light vacuum (-0.05 MPa) on a Multivac packing machine (Sepp Haggenmüller KG, Wolfertschwenden, Germany), and placed in a domestic freezer for storage at -24C. Packed frozen samples were thawed in a Samsung M1712N microwave oven (Samsung Electronics S.A., Madrid, Spain). Samples were heated for 20 min at an output power rating of 600 W.

Sensory Evaluation

Three sensory descriptive methodologies were performed by panels with varying degrees of training. The idea was to choose “the worse situation” to check if semi-trained and untrained assessors could give a relevant and similar product mapping than a trained panel with the advantage of saving time and effort. In each methodology, the seven PPs were served in white plastic vessels, coded with a three digit number, at a temperature of 55 ± 1C, as previous studies showed that this is preferred temperature for PP consumption (Alvarez *et al*. 2011a,b, 2012). After thawing, samples were brought up to 55C and kept at this temperature by placing them in a Hetofrig CB60VS water bath (Heto Lab Equipment A/S, BirkerØd, Denmark) prior to tasting, where water and product temperatures were monitored by T-type thermocouples. For the FP and PM panels, all samples were presented at the same time. Mineral water was at assessors’ disposal to rinse their palate between samples.

QDA. *Selection of Descriptors, Assessors’ Training and Samples Evaluation.* A trained sensory panel of eight assessors tested the seven PP samples. Nevertheless, there was difference in the training experience and time of the assessors. Four of them had extensive previous experience (more than 7 years) in both QDA and texture profile (TP) of PP samples (Fernández *et al*. 2008; Alvarez *et al*. 2011b), whereas the rest had been trained specifically in TP of PPs for 1 year in accordance with ISO (1993). For that reason, the development of a common language for the description of the texture of PPs had been earlier consensual and discussed by the complete panel. An initial list of terms was prepared by combining the descriptors included in a TP developed (Alvarez *et al*. 2011b) with those used in a previous QDA (Fernández *et al*. 2008), which had been adapted to evaluate PP products from Adams *et al*. (1981). Three 3-h sessions were held during which the seven PP samples were presented to the assessors and they were asked to evaluate the suitability of all the preselected terms to describe the sensory characteristics of the PPs according to the checklist method (Damasio and Costell 1991). During these sessions, many attributes were left aside by the majority vote of the panel either by lack of consensus or because of the difficulty in comprehension or evaluation procedure. A list, composed of 13 terms regarding texture, taste and color of the samples was finally selected (Table 2). None of the panel members had any problem in conceptualizing, defining and training themselves in these attributes. Subsequently, consensus on the tasting procedure as well as agreement upon how to quantify the intensity of all the attributes was reached after 1-hour session.

QDA of the seven samples was carried out in duplicate over 14 sessions at a fixed time (1:00 p.m.), and each assessor evaluated one sample (about 50 g each) per session. However, the PP sample without more added ingredients (C sample) was presented every day for reference together with the corresponding daily sample. This process allowed the assessors to create the appropriate context for each scale. Panelists rated the intensity of the 13 attributes on a structured 8-cm line scale labeled at each anchor with the end terms shown in Table 2 (e.g., for visual graininess, left anchor: 1 = ‘‘smooth”; right anchor: 9 = ‘‘grainy’’, etc.). For each sample, textural attributes were evaluated first. Then, assessors were asked to evaluate taste, and finally, color attributes.

FP. *Panel and Samples Evaluation.* FP was carried out by 30 semi-trained assessors with experience in sensory description of other food products (not PPs); they were recruited among students and employees of the Institute of Food Science, Technology and Nutrition (ICTAN-CSIC). FP consisted of two sessions in which the seven samples were presented all at the same time. During the first session, the assessors were given an explanation about the procedure. Then, the assessors were asked to taste and examine the samples in order to generate their own provisional list of attributes individually, which should be sufficiently discriminant to allow a ranking of the samples. The assessors were instructed to avoid hedonic terms; in the second session they assessed the seven PPs, ranking all samples from "least" to "most" according to each attribute (ties were allowed).

PM. *Panel and Samples Evaluation.* PM was carried out by 30 untrained students and employees of the Institute of Food Science, Technology and Nutrition (ICTAN-CSIC) (27-56) years old. Members of the untrained panel were different from those who took part in the FP task. Assessors had no previous experience in sensory assessment. The 30 untrained assessors were acceptors, frequent consumers of potato products and not rejecters of milk. The seven PP samples were simultaneously presented to each judge placed in the middle of an A3 (29.7 × 42 cm) sheet. Assessors were given verbal instructions and allowed to ask for clarification before they began. Instructions were as follows: taste and examine the PPs and arrange the vessels of the paper in such a way that those which are similar are close together, and those very different are far apart. Do this according to whatever terms or attributes you choose. PM exercise was combined with ultra-flash profiling: after placing them on the sheet, assessors were asked to describe the individual products or groups by directly writing on the sheet as a means to describe the differences or sensory characteristics. Ultra-flash profiling has been used by other authors (Perrin *et al*. 2008; Moussaoui and Varela 2010;

TABLE 2. SCALE END TERMS AND DEFINITIONS OF ATTRIBUTES USED IN THE QUANTITATIVE DESCRIPTION BY THE TRAINED PANEL (QDA) OF POTATO PUREE SAMPLES

Attribute	End terms	Definition
Texture		
Visual graininess	Smooth-grainy	Geometrical textural attribute reflecting the size and shape of the particles
Creaminess	Not perceived-intense	Combined perception of fat, smoothness and viscosity
Moisture	Dry-watery	Surface textural attribute reflecting the water content of the potato puree
Firmness	Low-high	Mechanical textural attribute relating to the force required to achieve a given deformation, penetration, or breakage of the potato puree
Cohesiveness	Low-high	Mechanical textural attribute reflecting the effort required to reduce the potato puree to a state suitable for swallowing, taking into account the potato's resistance to disintegration
Adhesiveness	Low-high	Mechanical textural attribute reflecting the effort required to separate the potato puree from any surface inside the mouth (teeth, gums, palate); the intensity is perceived as the level of force required to separate the compressed sample from bucal surfaces (especially the palate) with the tongue.
Fibrousness	Smooth-grainy	Geometrical textural attribute reflecting the graininess perceived during preparation of the sample in the mouth prior to swallowing
Ease of swallowing	Low-high	Property reflecting the ease with which the potato puree is transferred to the back of the palate and swallowed.
Mouth coating	Not perceived-intense	The mouthfeel of the product, once swallowed, consists in the perception of a thin layer covering the palate
Taste		
Authentic taste	Not perceived-intense	Taste associated with potato puree control, i.e. without more added ingredients
Off-taste	Not perceived-intense	Atypical taste often associated with deterioration or transformation of the product
Color		
Off-colors	Not perceived-intense	Atypical color often associated with deterioration or transformation of the product
Shine intensity	Weak-intense	Magnitude of the shine perceived

Albert *et al*. 2011) as a good complement to PM. Data were collected manually as the x- and y-coordinates to the center of each vessel from the lower left corner of the paper. The aim of this test was profile the products with the use of consumers' words.

Texture Profile Analysis.

Texture profile analysis (TPA) was performed using a TA.HDPlus Texture Analyser (Stable Micro Systems Ltd, Godalming, U.K.) equipped with a 300 N load cell. During tests, PPs were kept at 55C by means of a Temperature Controlled Peltier Cabinet (XT/PC) coupled to a separate heat exchanger and proportional-integral-derivative control unit. For performance of TPA tests, an aluminium cylindrical probe (P/35) with 35 mm diameter was driven into a 60 mm diameter stainless steel vessel containing 50 ± 1 g of sample. Samples were compressed to 33% of initial height at a compression speed of 3 mm/s, with a rest period of 5 s between cycles. Previous studies showed that under these conditions the action of the jaw is properly imitated (Canet *et al*. 2011). Consistency (N), adhesiveness (N s), springiness (dimensionless), cohesiveness (dimensionless) and gumminess (N) were reported for each sample. In this study, hardness was termed consistency following Kramer (1973), who suggested that since food slurries such as sauces are invariably non-Newtonian, this characteristic could properly be called "consistency." Texture measurements were performed in quadruplicate and results averaged.

Statistical Analysis

QDA data were analyzed using two-way mixed-model analysis of variance (ANOVA) on the attributes rated by the trained panel to analyze sample and assessor effects and their interaction, assuming that either main effects or interaction were fixed effects. Significant differences between samples were determined by the Fisher's least significant difference test at 5%. Principal component analysis (PCA) based on the Pearson's correlation matrix was conducted on the mean values of attribute intensities presenting significant differences. PCA is a statistical tool that helps to summarize, and therefore communicates better the results from descriptive panel profiling (Moussaoui and Varela 2010).

For the FP data, individual matrices for each assessor (samples x attributes) were built in order to enter product rankings. A generalized Procrustes analysis (GPA) (Gower 1975) was then performed on the 30 matrices in order to obtain the sample and attribute configurations.

The projective maps from each assessor obtained by the PM were analyzed by multiple factor analysis (MFA) (Pagès and Husson 2001). MFA was performed on data obtained from the positioning of the seven samples on the A3 sheets as well as the attributes each assessor generated to describe the samples. The sample coordinates were measured in centimeters and attributes listed together with their frequencies of mention across the untrained panel, resulting in three tables: x, y, attributes. Frequency of mention scores of synonyms and repeated sensory attributes were combined and considered as one variable in the data analysis (i.e., authentic taste, potato taste, natural taste, homemade taste would be entered as authentic taste with a frequency of mention that is the sum of the frequencies of each word). MFA was performed for each assessor incorporating the descriptive analysis data of the ultra-flash profile as supplementary variables (Perrin *et al*. 2008).

Following PCA, GPA and MFA, hierarchical clustering analysis (HCA) was carried out on the sample mean configuration coordinates in order to highlight sample clusters as perceived by the three panels. Clustering parameters were dissimilarity, Euclidean distance and agglomeration method: Ward's method and automatic truncation (Albert *et al*. 2011).

On the other hand, semi-trained and untrained panel maps were correlated with the trained panel map using a MFA in such a way that mean scores from the trained panel were considered as an additional data set to nonexperienced individual data. The regression vector (Rv) coefficient was also used to compare the agreement in the structure of the configurations determined by the evaluations of the three panels. Rv coefficient has values between 0 and 1 with numbers closer to 1 indicating greater similarity. Moreover, sensory data from each of the three methods were analyzed jointly with instrumental data from TPA tests using MFA (Escofier and Pagés 1990). In this analysis, only those attributes generated by the three panels that described textural characteristics of the samples were taken into account.

All data analyses were carried out with XLSTAT add-in for Microsoft Excel software version 2012 (Addinsoft, Paris, France).

RESULTS AND DISCUSSION

QDA – Trained Panel

A definitive list with the 13 attributes was created by consensus (Table 2). An important point to note here is that there was difference in the training experience and time of the assessors; therefore it is important to know whether assessor variability may influence the estimation of sample differences. Two-way mixed-model ANOVA analysis (Table 3) showed that the 13 attributes evaluated differed among samples ($P < 0.05$). Assessors were not a significant source of variation for any of attributes studied. There was a good level of agreement among the new assessors and the four earlier members regarding their evaluations, i.e., no lack of concordance within the panel ratings was observed.

Figure 1 shows the relative positioning of the samples and attributes in the sensory space generated by the trained panel. PCA of descriptive data revealed a clear discrimination of the sample set following the average ratings of the 13 attributes. Results showed that the first component explained 87.2% of the total variability and was mainly relate to texture attributes. Looking at how the samples were positioned in the bidimensional space, samples with added both EVOO and INL ingredients, either alone or blended, showed higher creaminess and ease of swallowing, and were perceived as having more intense shine than the samples with added SPI, either alone or blended with INL or EVOO, which showed higher visual graininess, firmness, adhesiveness, cohesiveness, fibrousness and mouth coating. This coincides with the observation by Alvarez *et al*. (2011b) that addition of EVOO oil significantly enhances the texture of PP samples. Alvarez *et al*. (2012) also found that the presence of SPI strands was a dominant factor in texture perception of PP with regard to the mouthfeel geometric attribute (fibrousness) and the after-feel attribute (mouth coating), while presence of INL crystallites was the most important feature increasing creaminess, moisture and overall acceptability. In turn, milk beverage model systems with added INL were perceived as significantly creamier than samples without INL (Villegas *et al*. 2007).

In turn, the second component explained 7.8% of total variability and was defined mainly by taste attributes and as well by moisture. In the upper part, there was the control (C sample) that was perceived as having more authentic taste than the rest of samples due to the strong potato flavor detected in the product. In turn, EVOO + INL sample was perceived to be the moistest. It can also be observed that either off-taste or off-colors described PPs with added EVOO + SPI blend, indicating that the addition of these two ingredients together produced an unpleasant either taste or color.

TABLE 3. TWO-WAY MIXED ANALYSIS OF VARIANCE ON THE SENSORY ATTRIBUTES RATED BY THE TRAINED PANEL (SEVEN SAMPLES, EIGHT ASSESSORS, TWO REPLICATES). *F* AND *P* VALUES

	Sample (df = 6)		Assessor (df = 7)		Sample × Assessor (df = 30)	
Descriptor	*F value*	*P value*	*F value*	*P value*	*F value*	*P value*
Visual graininess	254.23	0.000	1.55	0.168	1.81	0.019
Creaminess	162.90	0.000	1.74	0.118	0.89	0.651
Moisture	178.30	0.000	0.40	0.900	0.97	0.544
Firmness	254.31	0.000	1.05	0.411	0.92	0.608
Cohesiveness	352.57	0.000	0.57	0.778	1.59	0.053
Adhesiveness	177.78	0.000	1.41	0.218	0.94	0.580
Fibrousness	308.89	0.000	0.72	0.659	0.87	0.684
Ease of swallowing	117.29	0.000	0.73	0.649	0.61	0.954
Mouth coating	244.17	0.000	0.96	0.469	1.01	0.475
Authentic taste	393.01	0.000	0.58	0.770	1.24	0.227
Off-taste	936.20	0.000	0.66	0.704	1.09	0.375
Off-colors	560.02	0.000	0.30	0.953	0.83	0.730
Shine intensity	401.07	0.000	0.67	0.696	0.93	0.593

***F* values calculated considering main effects and interaction as fixed parameters.**

HCA grouped the most similar samples into three main clusters reported on the sensory map (ellipses shown in Fig.1). The trained panel clustered the samples using the two axes of the biplot. Cluster 1 grouped only C sample, following the second dimension of the PCA. Cluster 2 was a group of PPs enriched with both EVOO and INL, either alone or blended, while cluster 3 was a group of PP samples enriched with SPI, either alone or blended with INL or EVOO. Therefore, clusters 2 and 3 were separated by presence or absence of SPI, mainly by their textural characters. Results show that the addition of EVOO, INL and SPI, either individually or blended, affect intensity of texture attributes more than taste and color attributes, although no systematic differences in texture variation can be established between samples with added EVOO and INL alone. The latter result evidences that long-chain INL could be used as a fat substitute, "as *fat mimetic*", with a capacity that is practically double that of native INL (Franck 2002). This property is attributed to its capacity to form microcrystals that interact with each other forming small aggregates that occlude a great amount of water (Villegas *et al*. 2007).

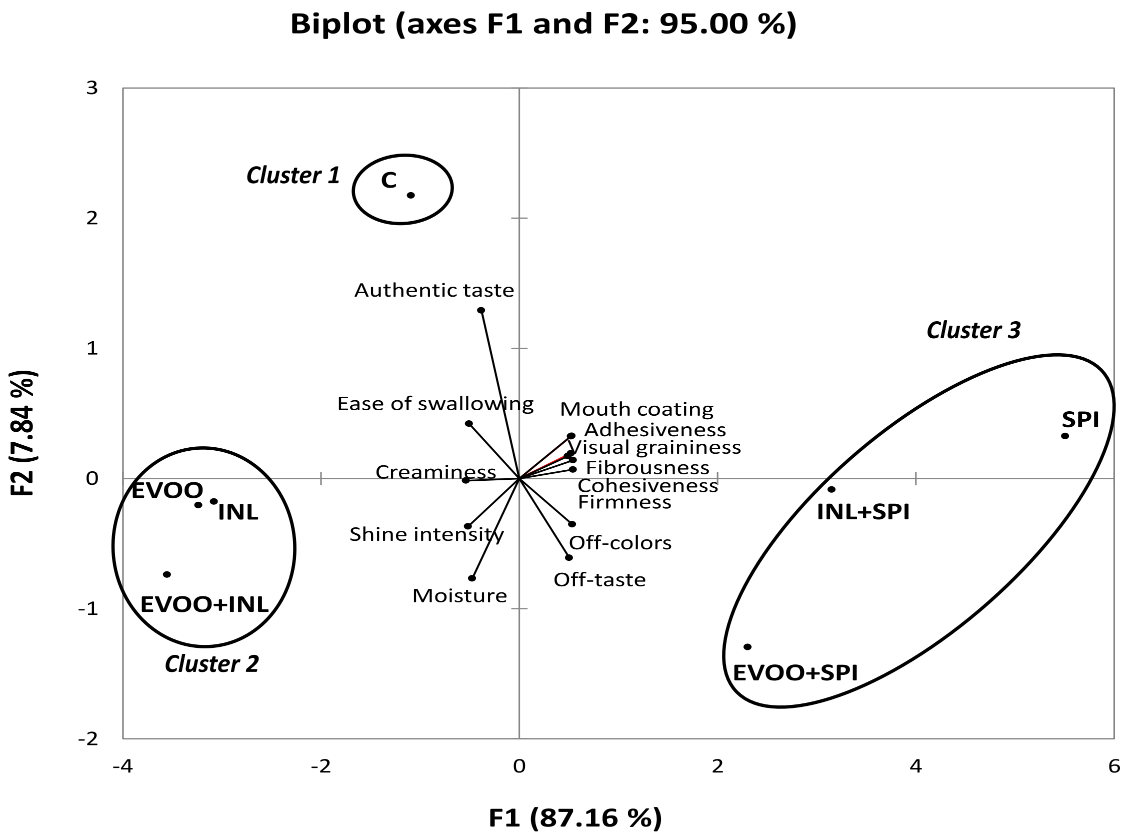

FIG. 1. PRINCIPAL COMPONENT ANALYSIS BIPLOT OF QUANTITATIVE DESCRIPTIVE ANAYSIS FOR POTATO PUREE SAMPLES WITH ADDED EXTRA VIRGIN OLIVE OIL (EVOO), INULIN (INL), SOY PROTEIN ISOLATE (SPI) AND THEIR BLENDS. C: CONTROL SAMPLE

FP – Semi -Trained Panel

Each assessor created an average of eight terms. From the 240 terms originally generated by the assessors, only 74 terms were included in the analysis. This is why the repetitive terms used by the different assessors were considered only one time. Examination of the sensory space obtained by GPA from the FP data indicated that the first two dimensions accounted for the 83% of the total variability (Fig. 2). The first dimension appears to be a contrast between samples with added SPI, either alone or blended with EVOO or INL, and the rest of the samples, and involved multivariate perceptions (texture, taste and appearance) grouping in the negative part attributes as sandy, earthy, pasty, palate coating, grainy, off-taste, off-colors and visual opacity. C sample and those enriched with both INL and EVOO, either alone or blended, showed higher creaminess, aqueous texture, easy of swallowing, and characteristics of homemade products and better general appearance than samples with added SPI. The second dimension was defined mainly by taste attributes. Samples with added EVOO were perceived as having oilier odor and taste, while C sample, in the lower part of this dimension, was perceived as having more intense puree odor and taste notes. Anyway, note as quite attributes correlated to both dimensions.

Sample clustering obtained with HCA showed three groups as the one obtained from QDA results. Cluster 1 was a group enclosing C sample and sample with added INL alone. This is probably because assessors were able to perceive the darkening caused by either SPI or EVOO addition. In the FP method, description is obtained from a ranking of the products, attribute per attribute (Perrin and Pagès 2009). PPs with added SPI were perceived darker brown in color, whereas the samples with added EVOO were yellower in color, which was previously associated with augmented pigment content (Alvarez *et al*. 2011b). In contrast, INL is a white powder and produced a lighter colored PP than the control. Probably, for this reason, semi-trained panel perceived the color of PP samples with added INL alone as being more similar to C sample characteristic color, as Kennebec potatoes have a white flesh and PPs without more added ingredients look also quite pale. In turn, cluster 2 was a group of samples enriched with both EVOO alone and the EVOO + INL blend, and finally the samples with added SPI were clustered in a group 3. As a result, samples with added SPI were perceived as more adhesive, dense, firm, fibrous and sandy, while the samples with added either INL or EVOO alone were perceived as less sticky, firm and fibrous, and, in contrast, the most creamy and aqueous. The presence of EVOO was also separated along the second dimension. The samples with added EVOO alone and with added EVOO + INL blend characterized by attributes mainly relate to oily taste and odor. In addition, as it was also observed in the QDA outcome, semi-trained panel also perceived the samples with added EVOO + SPI blend as having a rancid taste and aroma.

PM – Untrained Panel

There were 55 terms originally generated by the untrained panel, although only 38 different attributes were considered in the MFA of the PM data. Seventeen terms related with hedonic descriptions were eliminated, and synonyms used by different assessors were combined into one term. As made by semi-trained assessors, untrained ones also used their own terms with a more spontaneous and varied generation of attributes as compared to trained assessors. When MFA was applied to the PM task, the first two components accounted for 76.7% of the variability. As found by Albert *et al*. (2011), variability explained is lower than those obtained by QDA and FP. The latter authors attributed this fact to differences between panels in previous experience.

Figure 3 shows the correlation circle MFA of the PM together the results of the HCA performed on attributes. As in the FP task, the first dimension separates samples with added SPI, either alone or blended with EVOO or INL, and the rest of samples. This dimension grouped attributes such as palate coating, pasty, off-taste, adhesive, adherent, rancid taste and rancid smell, which were in the negative part. In the positive part of the first dimension were positioned the C sample and those enriched with both INL and EVOO, either alone or blended. The second dimension was defined mainly by taste and aroma attributes and C sample was in the upper part of this dimension. Certainly, untrained panelists showed evidence of a high purchase intent towards the control (different assessors commented that definitely would buy it), which was associated with its excellent aroma and taste, and referred to with the term “commercial”.

Moreover, sample clustering obtained with the HCA another time revealed 3 groups. Cluster 1 was a group enclosing C sample and those enriched with INL alone, and were accordingly described by aroma and taste attributes. Cluster 2 was a group of samples with added EVOO, either alone or blended with INL, whereas cluster 3 grouped PPs enriched with SPI, either alone or blended with INL or EVOO. Therefore, the third cluster was separated from the other two ones in response to SPI presence. As a result, all the samples with added SPI were perceived as more pasty than the samples with added both INL and EVOO, either alone or blended. In turn, samples enriched with both EVOO alone and EVOO + INL blend were described by attributes related to oil and smooth taste and smooth texture, whereas samples with added both INL alone and EVOO + INL blend were perceived as more creamy and watery, easier to swallow and with a natural aroma. Finally, as found in the QDA and FP outcomes, samples with added SPI blended either with INL or with EVOO were perceived as having a taste and smell rancid.

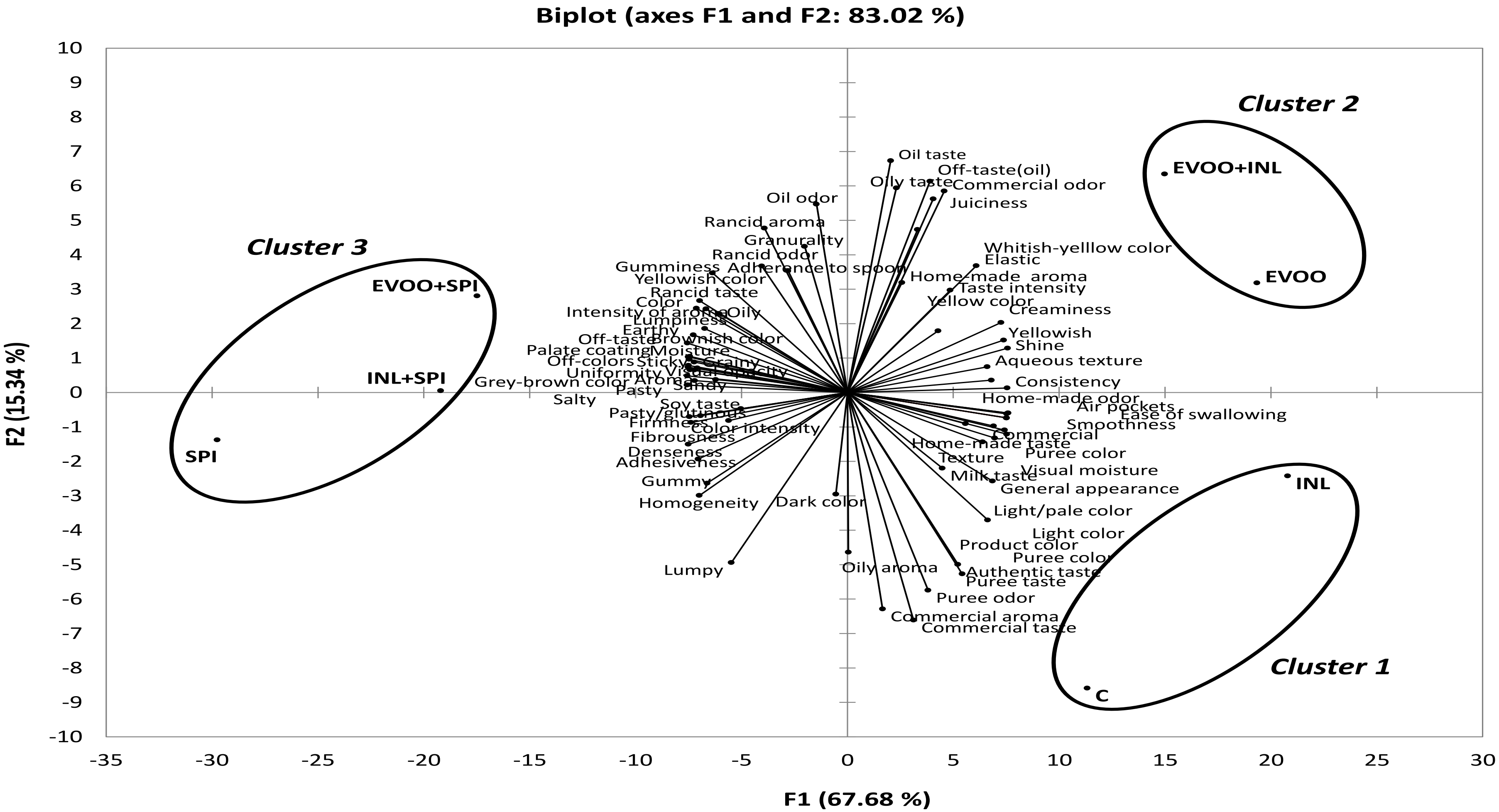

FIG. 2. GENERALIZED PROCRUSTES ANALYSIS BIPLOT OF FLASH PROFILING FOR POTATO PUREE SAMPLES WITH ADDED EXTRA VIRGIN OLIVE OIL (EVOO), INULIN (INL), SOY PROTEIN ISOLATE (SPI) AND THEIR BLENDS. C: CONTROL SAMPLE

Comparison of Results from the Three Panels

The comparison of the three sensory spaces generated by each of the panels was treated as a multi-block analysis via MFA (Moussaoui and Varela 2010; Worch *et al*. 2010). In turn, the calculation of the Rv coefficients for each pair of methods allows quantifying the overall similarity between the resulting sensory configurations measured on the same samples (Robert and Escoufier 1976; Schlich 1996).

In this study, the correlation map of trained panel with both semi-trained and untrained panel results showed that the two first dimensions explained up to 84% of the variability for

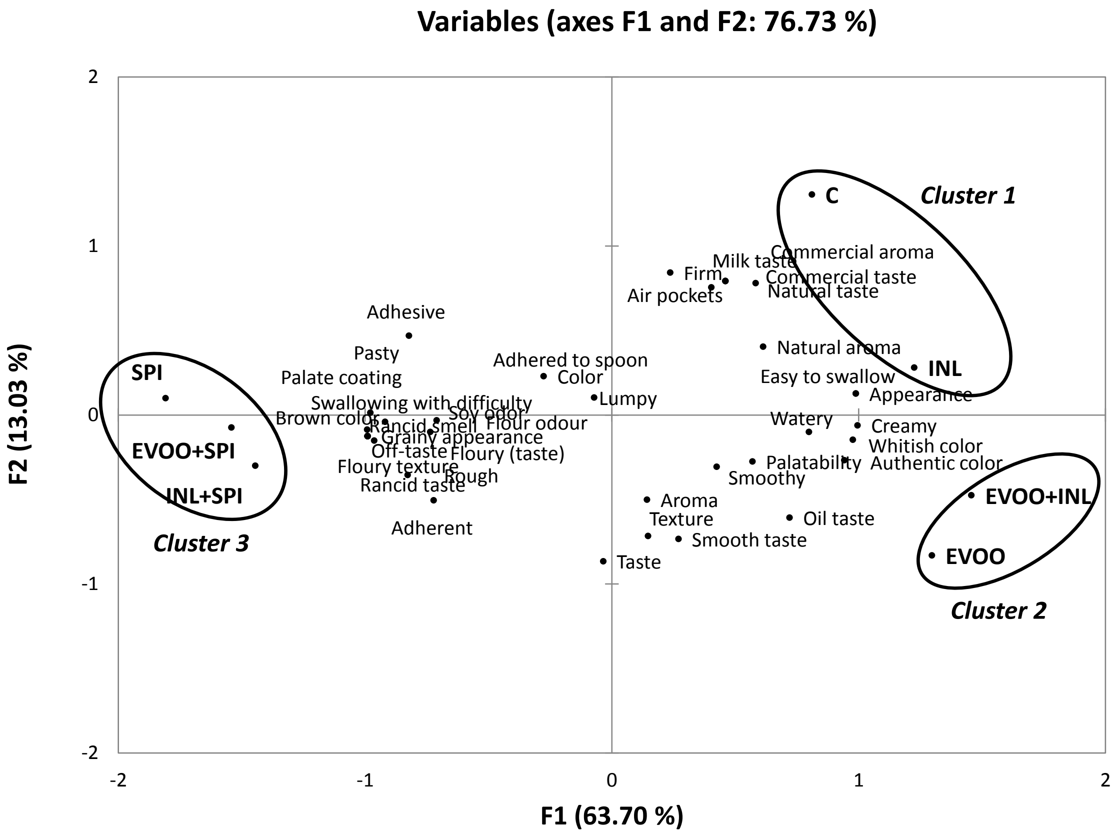

FIG. 3. MULTIPLE FACTOR ANALYSIS BIPLOT OF PROJECTIVE MAPPING FOR POTATO PUREE SAMPLES WITH ADDED EXTRA VIRGIN OLIVE OIL (EVOO), INULIN (INL), SOY PROTEIN ISOLATE (SPI) AND THEIR BLENDS. C: CONTROL SAMPLE

FP and 83% for PM. The two Rv coefficients were greater than or equal to 0.90 (Rv for QDA versus FP was 0.92 and for QDA versus PM was 0.90), indicating that there was good agreement across the two pairs of comparisons. Anyway, FP sensory space was further similar to that of QDA than was the PM one. Albert *et al*. (2011) obtained a little lower Rv coefficients in the comparison of the sensory spaces generated by the same three methods for fish nuggets (Rv for QDA versus FP was 0.86 and for QDA versus PM was 0.82). In turn, in hot beverages, Moussaoui and Varela (2010) obtained a Rv value of 0.91 when comparing the sensory spaces generated by a trained panel (via QDA) versus a consumer panel (via FP).

Superimposed representation of the attributes evaluated by both QDA and FP methods, shown in the Fig. 4, allows the evaluation of the relationships between them. The equivalent attributes "adhesiveness" (r = 0.95), "fibrousness" (r = 0.86), "creaminess" (r = 0.95), "off-colors" (r = 0.95) and "off-taste" (r = 0.89) generated by both panels were located close, suggesting a high correlation between both evaluations. For six commercial milk desserts, also a high correlation between "creaminess" evaluated by consumers and trained assessors was found, which indicated that the definition given by the trained assessors' panel could be close to consumers' creaminess perception (Bruzzone *et al*. 2012). Certainly, in the comparison between QDA and FP panels, no disagreement was found between the assessors of both panels for any of the equivalent attributes generated. This suggests that, even though semi-trained assessors had not experience in sensory description of PP samples, they were able to evaluate them in a similar way as trained assessors did.

In turn, Fig. 5 shows the comparison between the sensory spaces generated by both trained and untrained panels. Furthermore, the attributes' representation showed high correlation between equivalent attributes. For instance, the attributes "creaminess" and "creamy" appear to be high and positively correlated (r = 0.93). The same occurs for the pairs of terms “ease of swallowing” and “easy to swallow” (r = 0.98), “moisture” and “watery” (r = 0.80), “adhesiveness” and “adhesive” (r = 0.92) and “mouth coating” and “palate coating” (r = 0.91). In PP samples subjected to sensory TP, an untrained panel was able to distinguish between PP samples with different added SPI:INL ratios, but only a good linear correlation was observed between trained and untrained evaluations for “creaminess” (Alvarez *et al*. 2012). Nevertheless, a disagreement between both trained and untrained panels was observed for the pair of the terms “firmness” and “firm” (r = -0.07). Interestingly, and in contrast, “firmness” was highly correlated with “pasty” (r = 0.98); this allows the observation that the “firmness” perception was not quite well described by untrained assessors.

On the other hand, the MFA partial points representation of the samples evaluated by QDA and FP methods (Fig. 6a), shows that PPs with greater variability are both C and INL samples because the semi-trained panel discriminates these products better in the second dimension, whereas trained panelists discriminate the INL sample better in the first one (Figs. 1 and 2). In turn, the MFA partial points graph of the samples evaluated by QDA and PM methods (Fig. 6b) shows that PPs with more variability are both C and SPI samples, even though in this case both trained and untrained panels discriminate these two samples well again in similar dimensions (Figs. 1 and 3). Anyway, SPI sample rated by the trained panel is opposed to the same sample rated by the untrained panel. Despite these disagreements, Rv coefficients between both nonexpert and trained panels are high, which shows that the disagreement is minimal and concern only two PP samples in both comparisons. Therefore, it would be possible state that the attributes generated by the semi-trained and untrained panels reflected well those used by the trained panel, and the samples spaces are in fact close. Similar results were observed in the comparison of sensory profiles of perfumes (Worch *et al.* 2010), hot beverages (Moussaoui and Varela 2010) and hot fish nuggets (Albert *et al.* 2011).

Relationships between Sensory and Instrumental Data

MFA was used to analyze both texture sensory and instrumental data (Escofier and Pagès 1990; Lassoued *et al*. 2008). Figure 7 shows the correlation circles between the texture attributes generated by the three panels (via QDA, FP and PM) and the TPA test performed. It can be seen that the two first dimensions explained the 95% of the variance for the QDA, the 85% for the FP and the 80% for the PM. The Rv coefficients showed a good agreement across the three texture sensory spaces and the TPA parameters. The highest correlation was found for QDA versus TPA (0.89) and the lowest for PM versus TPA (0.75). This result is not surprising since the QDA panel was also highly trained in TP of PP samples, and therefore assessors tended to be very detail oriented regarding textural parameters.

Between the QDA attributes (Fig. 7a), mouth coating (r = 0.99), firmness (r = 0.97), adhesiveness (r = -0.95) and fibrousness (r = 0.91) were high and positively correlated with TPA consistency. In the case of adhesiveness, correlation is negative because the instrumental parameter measures a negative area. In turn, Fig. 7b shows that between the FP attributes, denseness (r = 0.98), consistency (r = 0.82) and firmness (r = 0.80) were also high and positively correlated with consistency from TPA. Between the PM attributes (Fig. 7c), pasty and palate coating (r = 0.94 in both cases) were high and positively correlated with TPA consistency, and again both sensory and instrumental adhesiveness were negatively related (r = -0.83). A high correlation was also found between sensory hardness evaluated by a trained panel and TPA hardness for cooked sweet potatoes (Truong *et al*. 1997).

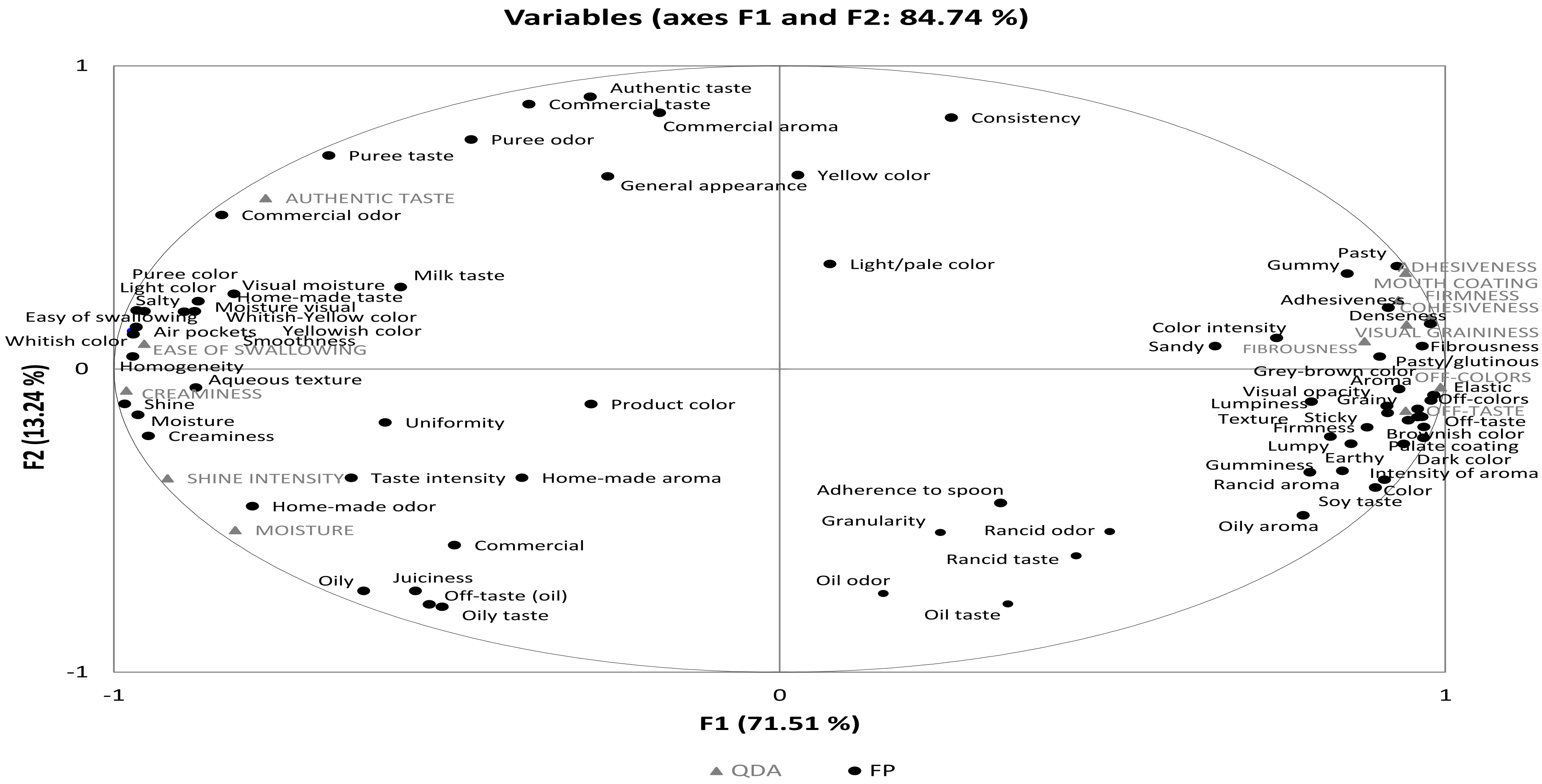

FIG. 4. COMPARATIVE MULTIPLE FACTOR ANALYSIS PERFORMED SIMULTANEOUSLY ON DATA FROM QUANTITATIVE DESCRIPTIVE ANALYSIS (QDA) AND FLASH PROFILE (FP). REPRESENTATION OF THE ATTRIBUTES GENERATED BY TRAINED AND SEMI-TRAINED PANELS

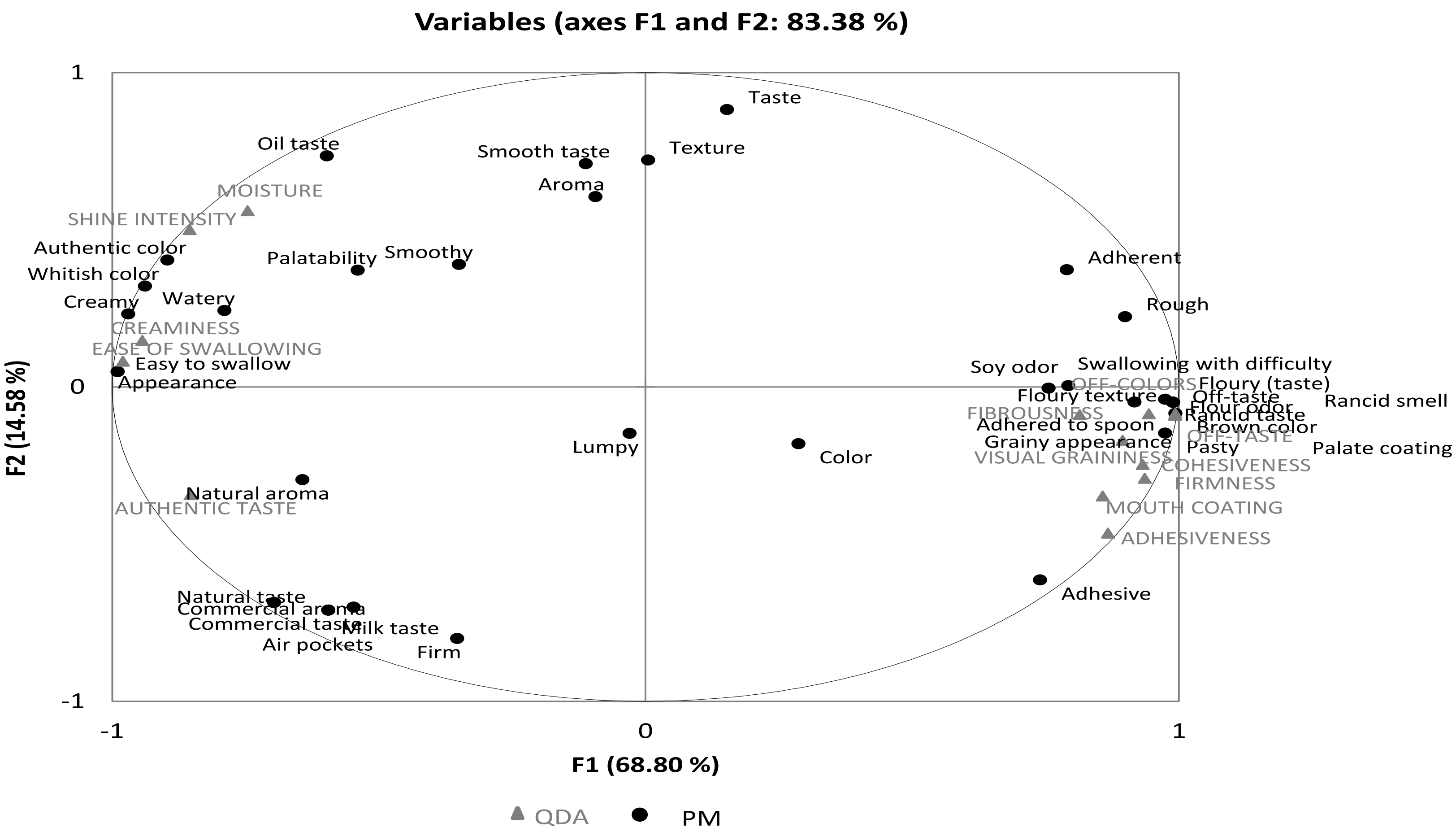

FIG. 5. COMPARATIVE MULTIPLE FACTOR ANALYSIS PERFORMED SIMULTANEOUSLY ON DATA FROM QUANTITATIVE DESCRIPTIVE ANALYSIS (QDA) AND PROJECTIVE MAPPING (PM). REPRESENTATION OF THE ATTRIBUTES GENERATED BY TRAINED AND UNTRAINED PANELS

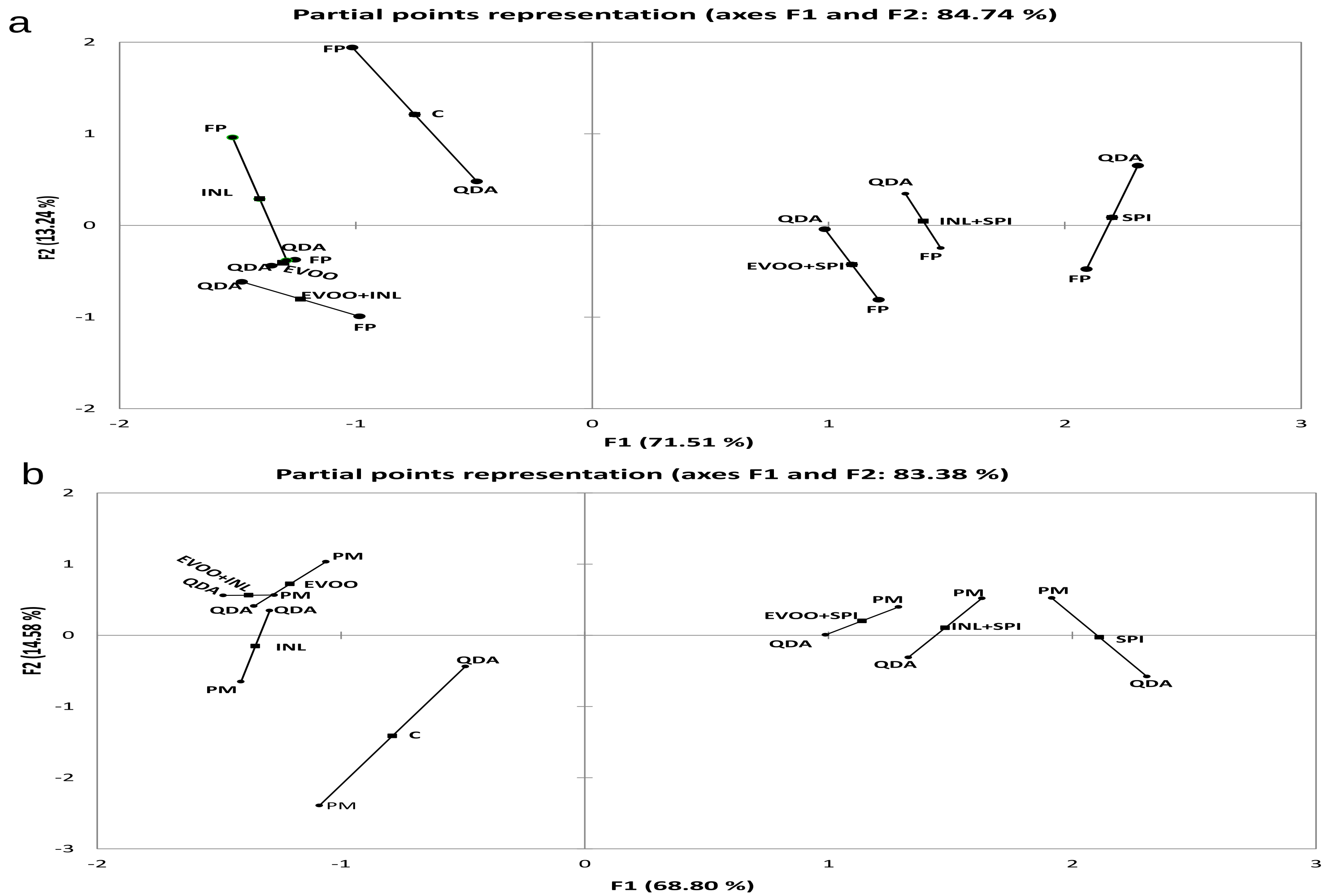

FIG. 6. COMPARISON OF THE PARTIAL POINTS REPRESENTATION THROUGH MULTIPLE FACTOR ANALYSIS.

(a) Representation of the trained and semi-trained products space. (b) Representation of the trained and untrained products space.

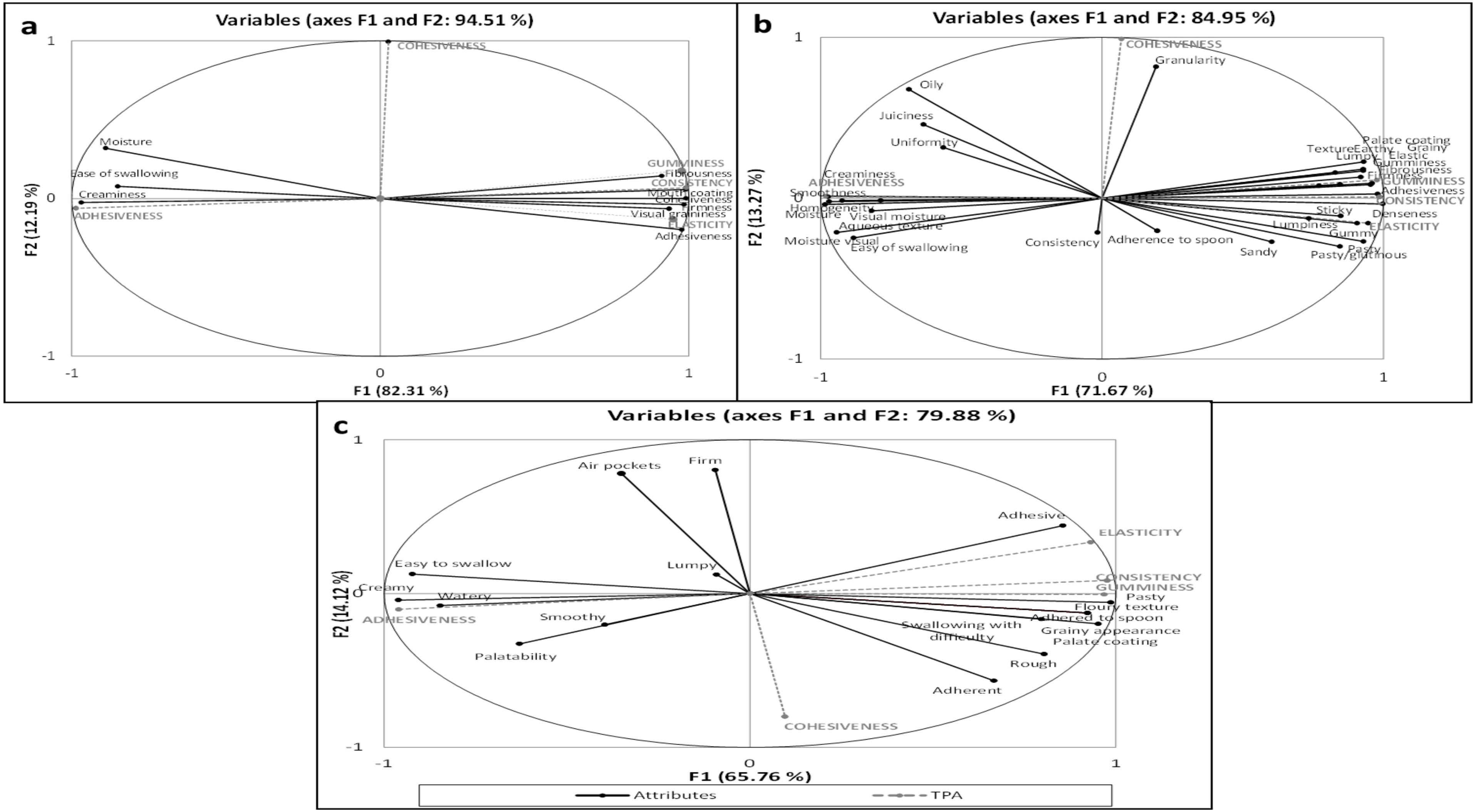

FIG. 7. CORRELATION BETWEEN INSTRUMENTAL DATA AND SENSORY ATTRIBUTES GENERATED BY (A) QUANTITATIVE DESCRIPTIVE ANALYSIS, (B) FLASH PROFILE AND (C) PROJECTIVE MAPPING

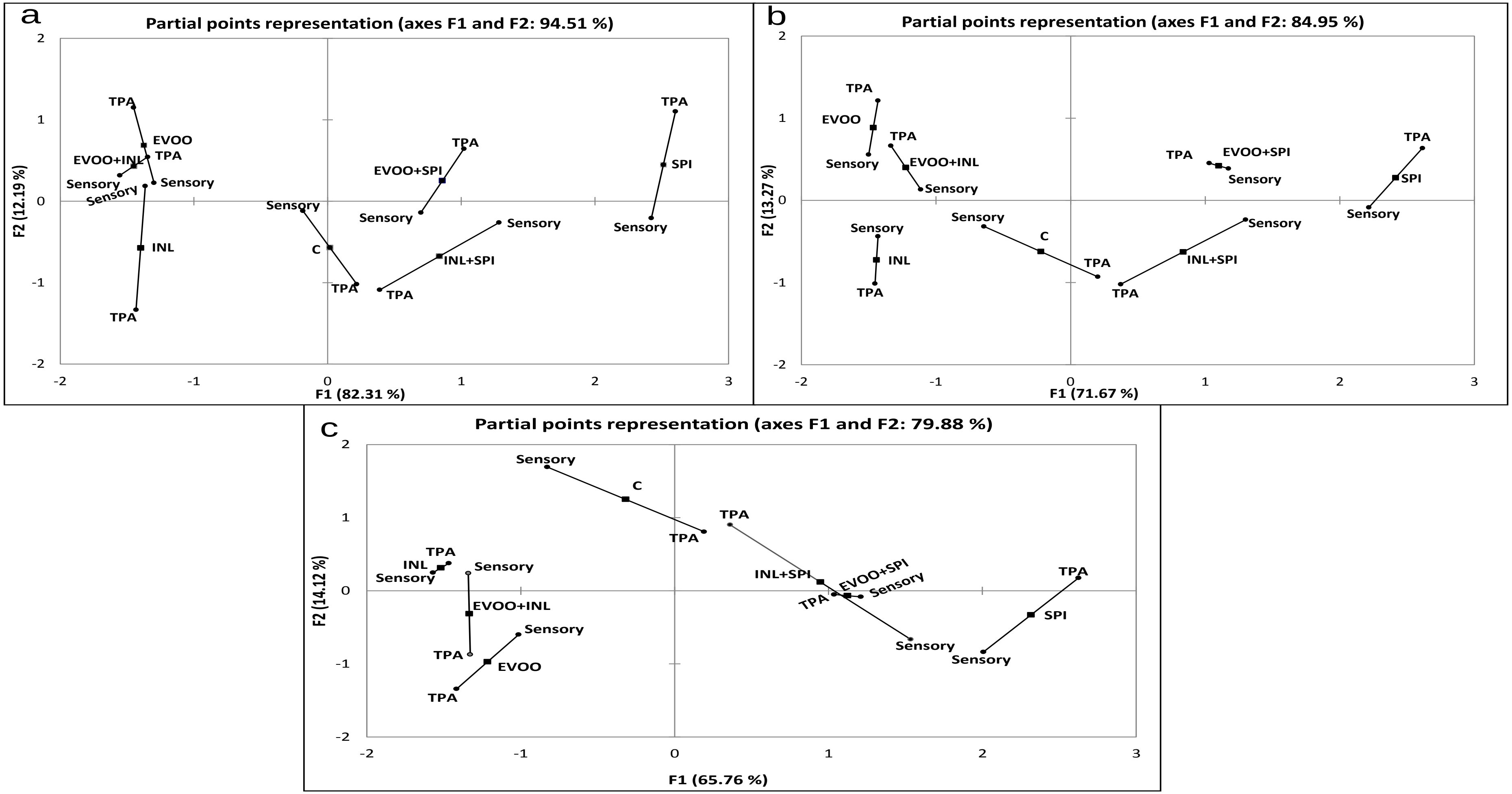

FIG. 8. FIRST-FACTORS MAP FROM MULTIPLE FACTOR ANALYSIS: REPRESENTATION OF PARTIAL POINTS: (A) QUANTITAVE DESCRIPTIVE ANALYSIS; (B) FLASH PROFILE; (C) PROJECTIVE MAPPING

Partial points' representations for QDA, FP and PM versus TPA (Fig. 8) show as to a given PP sample correspond two partial points, which reflect sensory and instrumental images. The proximity between these two images can be interpreted as coherence (Pagès and Husson 2005). In QDA, the two closest images correspond to EVOO + INL samples (Fig. 8a). In FP, images are closer to EVOO + SPI samples (Fig. 8b). In turn, in PM, both images are very close to either EVOO + SPI samples or to samples with added INL alone (Fig.8c). Therefore, at each sensory method, for cited samples, sensory and instrumental characteristics are more in agreement, and it can be said that the two measurements are coherent to each other. However, for the three sensory methods, the product that presented more discordance between sensory and instrumental characteristics was the INL + SPI sample. In all three cases, the first axis sets apart PPs with added SPI either alone or blended with INL or EVOO and PPs with added INL and EVOO either individually or combined between them whatever the adopted point of view (sensory or instrumental). Analogously, for QDA, FP and PM, the second axis sets apart the C sample.

CONCLUSION

Relative positioning of both samples and attributes in the three QDA, FP and PM sensory spaces was quite comparable. In all cases, there was an opposition between samples with presence or absence of SPI along the first dimension, so samples with added SPI, either alone or blended with INL or EVOO were separated from the rest, driven by textural attributes. In contrast, samples positioning along the second dimension was mostly dependant on color, aroma and taste characteristics. When clustering samples via HCA, products were grouped into three clusters in the three methods. Cluster 1 grouped only control sample (C) in the QDA, whereas samples with added INL alone were clustered with C sample in both FP and PM methodologies, mostly because of appearance and taste characteristics.

In turn, Rv coefficient between QDA versus FP was 0.92 and for QDA versus PM was 0.90, so there was a good agreement with QDA in both alternative methodologies, even though FP sensory space was further similar to that of QDA than was PM one. Higher correlations between textural attributes evaluated by trained and semi-trained panels were found, indicating that although semi-trained assessors had not experience in PPs texture description, they were able to evaluate them in a similar way as trained assessors did. Nevertheless, the untrained assessors' perception of 'firm/firmness' was not well correlated to the trained panel assessment. This finding suggests that there is a limit in the quality of information that can be obtained via consumers' description. In the study of the relation between the three texture sensory spaces and the TPA parameters, also lower correlation was found for PM versus TPA. Anyway, the difficulty with attributes coming from semi-trained and untrained assessors is that their real meaning and how they were measured is unknown, since only QDA panel knew the exact definition of all attributes.

In addition, there were various differences in the terms used by the three panels for sample description. When the terms distribution is compared by senses, it can be observed that the distribution is globally quite similar for FP and PM modalities. Appearance, taste, texture and odor represented over 25, 19, 40 and 15%, respectively, of the terms generated by semi-trained assessors, and above 16, 24, 45 and 16%, respectively, of the terms generated by untrained ones. Trained assessors generated the highest percentage of texture terms (69%), whereas appearance and taste represented over 15%, respectively, and they did not develop terms associated to odor. This can be explained as QDA panel was highly trained in texture assessment, whereas non-trained panels used more diverse and impulsive terms, making more references to the appearance and taste.

Accordingly, texture attributes were not the most relevant to the target consumers, whereas that trained assessors were inclined to look into samples details mostly related to texture neglecting other characteristics more obvious for the consumers (such as odor or appearance).

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CAPÍTULO 5

DISCUSIÓN INTEGRADORA

La presente tesis doctoral se enmarca dentro del proyecto de la Comisión Interministerial de Ciencia y Tecnología (Proyecto del Plan Nacional de I+D AGL2007-62851) titulado “Efecto de la adición de ingredientes funcionales en el comportamiento reológico y la textura de cremas y purés vegetales frescos y congelados”. En concreto, esta investigación se centra en el estudio del efecto de la adición de diferentes ingredientes funcionales y de sus mezclas en el comportamiento reológico, textura y propiedades sensoriales de puré de patata fresco y sometido a un proceso de congelación/descongelación, como consecuencia de la pérdida de calidad del producto que está asociada con esta tecnología.

Los resultados indicaron que las mejoras se pueden obtener afrontando diferentes líneas de actuación. Por un lado, están las intervenciones concretas en la formulación del alimento, es decir, la elección adecuada e incorporación de los diferentes ingredientes funcionales (aceite de oliva virgen extra, inulina, aislado de proteína de soja y sus mezclas) a una matriz (puré de patata) conocida e investigada previamente, y que posiblemente constituye la visión más clásica para abordar la mejora del alimento desde un punto de vista funcional y nutricional. Por otro lado, el desarrollo y la aplicación de metodologías sensoriales más innovadoras y rápidas, así como la aplicación de herramientas para la validación y correlación estadística de los datos obtenidos, constituye la aportación más innovadora de la presente memoria.

Efecto en la textura de los purés de patata de la adición de aceite de oliva virgen extra y crioprotectores.

El primer objetivo abordado en esta tesis consistió en evaluar los efectos ocasionados por la incorporación de aceite de oliva virgen extra y de crioprotectores en la estructura y textura de puré de patata, lo que suponía un compromiso entre, por un lado, tratar de reducir el daño mecánico asociado con la congelación/descongelación para obtener la adecuada textura en el producto final, y por otro, la elaboración de un producto cardiosaludable y con importantes propiedades antioxidantes. Para ello, se estudiaron los purés de patata elaborados con diferentes concentraciones de aceite de oliva virgen extra y con una mezcla de dos hidrocoloides (goma xantana y kappa-carragenato), evaluando cómo la presencia o ausencia de estos últimos, y la suplementación con el primero, afectaba a la textura, microestructura y, finalmente, a la aceptabilidad global de los productos frescos y procesados.

Los resultados de las medidas objetivas instrumentales de textura indicaron que tanto la *firmeza* (derivada del ensayo de extrusión inversa) como la *fuerza media* (derivada del ensayo de penetración cónica), aumentaban en las muestras elaboradas con crioprotectores y disminuían en aquellas que no contenían estos hidrocoloides, en comparación con sus valores en los correspondientes productos frescos, debido al procesado. Esto se explica debido al hecho de que las soluciones con goma xantana forman redes mucho más firmes y cohesivas cuando son congeladas y descongeladas. Ambas propiedades disminuyeron en las muestras tanto recién elaboradas como congeladas y descongeladas cuando se aumentó la concentración de aceite de oliva añadida, obteniéndose productos menos estructurados. El aumento de la concentración de aceite de oliva virgen extra produjo sistemas más líquidos, suaves y blandos, indicando que el aceite fluidifica y/o lubrica el puré de patata, como reflejan las medidas de *fuerza media* y de *firmeza* que fueron significativamente mayores en las muestras control sin aceite añadido.

En cuanto a las propiedades de color, los resultados revelaron que el incremento de aceite de oliva incrementó la *luminosidad* del puré, debido al aumento de la luz dispersada que está asociada con las propiedades de dispersión de la luz que posee la grasa. Además, debido al elevado contenido en pigmentos (clorofila a y b) del aceite de oliva, el incremento de éste ingrediente en el puré ocasionó que los productos fueran más verdosos y amarillentos.

El estudio del perfil sensorial de los purés formulados con aceite de oliva fue realizado mediante la técnica del perfil de textura que permitió evaluar los atributos según se percibían a lo largo del proceso de consumo del puré (en una fase visual antes de llegar a la boca, durante la masticación en boca, cuando se prepara el puré para ser ingerido y en una fase final y residual de la ingestión). Los resultados obtenidos de la evaluación realizada por 4 jueces entrenados indicaron que los tres factores estudiados (adición de aceite de oliva, adición de crioprotectores y procesado)**,** así como sus interacciones**,** tuvieron un efecto significativo en todos los atributos evaluados excepto en la *pegajosidad* (sólo afectada significativamente por la adición de crioprotectores) y el *recubrimiento del paladar* (afectado sólo significativamente por la adición de aceite de oliva). En una primera fase visual, los atributos evaluados fueron la *granulosidad* y la *humedad*. El primero disminuyó cuando se incrementó la concentración de aceite de oliva añadido, lo que se relaciona con las propiedades de lubricación y recubrimiento que confiere el aceite de oliva al puré de patata. El segundo, asimismo disminuyó en las muestras elaboradas con crioprotectores debido a la capacidad de éstos últimos para retener agua.

En una segunda etapa se evaluaron atributos percibidos durante la masticación del puré; los resultados indicaron una disminución de la *densidad* percibida y un incremento de la *homogeneidad*, con el incremento del aceite de oliva, mientras que no se observaron diferencias significativas en la *pegajosidad* del producto como consecuencia de este efecto. La percepción sensorial de los tres atributos evaluados durante la fase de preparación del puré para su ingestión (*cohesividad*, *adhesividad* y *fibrosidad*), disminuyó como consecuencia de la adición de concentraciones crecientes de aceite de oliva (> 10 g/kg). Esta reducción fue más significativa en presencia de los crioprotectores, y cuya presencia también disminuyó significativamente las diferencias en la *fibrosidad* percibida en los purés frescos y congelados/descongelados lo que probablemente esté relacionado con el hecho de que los hidrocoloides pueden transformar los sistemas desde un estado elástico de goma a un estado más fluido, reduciendo además la movilidad molecular y previniendo la retrogradación. Los resultados revelaron que las puntuaciones otorgadas tanto el atributo sensorial *facilidad de deglución* del puré, así como al *recubrimiento del paladar* que confiere el producto, se incrementaron con el aumento de la cantidad de aceite de oliva virgen extra añadida al producto.

En lo referente a la *aceptabilidad general*, los resultados indicaron que las muestras con cantidades elevadas de aceite tuvieron mayor aceptabilidad, atribuida a las notas aromáticas, *cremosidad* y sensación grasa en boca detectadas en esos purés, además de por la disminución de la sensación de sequedad y aspereza. Los panelistas también mostraron una mayor aceptabilidad hacia las muestras con crioprotectores añadidos, lo que probablemente esté relacionado con la sensación cremosa en boca que produce asimismo la goma xantana. Los resultados indicaron que las muestras más aceptables fueron aquellas elaboradas con 50 g/kg de aceite de oliva virgen extra. Sin embargo, en presencia de hidrocoloides es posible reducir el contenido de aceite de oliva por debajo incluso de 25 g/kg, sin que ello afecte a la aceptabilidad de estos productos de forma negativa.

Efecto en la textura de los purés de patata de la adición de mezclas de inulina y aceite de oliva virgen extra.

Puesto que la adición de aceite de oliva virgen extra a los purés de patata, estudiada en la anterior sección, produjo cambios en las propiedades texturales y organolépticas, así como en la aceptabilidad de estos productos, en esta segunda etapa de la tesis se propuso el estudio del efecto en dichas características de la adición de aceite de oliva junto con inulina, y de esta forma el objetivo fue obtener un producto rico en ácidos grasos saludables, un compuesto bioactivo (fibra soluble) y de alto valor nutricional. Por otro lado, se consideró que la adición de inulina y aceite de oliva de forma conjunta podría producir un alimento tecnológicamente mejorado, debido a la cremosidad proporcionada por la fibra soluble que da en boca una sensación similar a la de la grasa, y que previamente se comprobó que era del agrado de los consumidores.

Para ello, se prepararon un total de ocho formulaciones distintas de puré de patata: cinco de ellas eran mezclas de aceite de oliva e inulina con diferentes concentraciones de ambos, dos estaban elaboradas cada una con uno de los ingredientes de forma individual y una formulación se utilizó como muestra control, elaborándola sin ingredientes funcionales añadidos. Las ocho muestras se elaboraron con y sin crioprotectores, y se evaluaron inmediatamente después de su elaboración y tras un proceso de congelación/descongelación.

En primer lugar, se evaluaron las diferencias en las propiedades mecánicas de textura mediante un ensayo de extrusión inversa. Los resultados obtenidos de este ensayo indicaron que el efecto de las mezclas de aceite de oliva e inulina en estas propiedades es del mismo modo función tanto de la adición de crioprotectores como del procesado. Las muestras sin ingredientes funcionales añadidos tuvieron los valores máximos de *firmeza* e *índice de viscosidad*, y estos valores se vieron reducidos en mayor medida cuando sólo se añade la concentración más elevada de aceite de oliva (60 g/kg) que cuando se añade la misma cantidad de inulina. Por tanto, de forma individual el aceite de oliva produce sistemas más blandos que la inulina. Esta disminución puede esperarse debido a que con la adición de aceite de oliva se está aumentando la fracción de volumen de la fase oleosa, mientras que la explicación para la disminución en la consistencia de los purés con la adición de inulina puede ser atribuida a las altas temperaturas alcanzadas durante la cocción del puré; a temperaturas mayores de 80 ºC se produce una hidrólisis parcial de la inulina causando un predominio de moléculas cortas de inulina que no pueden formar zonas de unión fácilmente, lo que posiblemente justifica la consistencia más baja del puré enriquecido con inulina en comparación con las muestras control.

En cuanto a la adición de crioprotectores, los resultados mostraron que, excepto para la muestra control, la *firmeza* fue menor en las muestras sin hidrocoloides añadidos. Esto es debido a que la goma xantana, dadas sus propiedades gelificantes, produce unos sistemas más estructurados, aunque sin embargo estas diferencias en la *firmeza* entre las muestras con y sin crioprotectores son menores cuando la inulina se añade a una concentración elevada (ratios 60:0. 45:15 y 45:30). Por tanto, en ausencia de crioprotectores, la adición de inulina sola en cantidades mayores de 45 g/kg junto con aceite de oliva, produjo un espesamiento del puré. Tanto el aceite de oliva como la inulina se comportan como ingredientes que fluidifican el producto produciendo un ablandamiento de los purés, aunque cuando ambos ingredientes se añaden conjuntamente el ablandamiento es más dependiente de la concentración del aceite de oliva. También se observó una variación diferente de la *firmeza* en las muestras con y sin crioprotectores debido al procesado, produciéndose una disminución en la *firmeza* de las muestras sin crioprotectores cuando fueron congeladas y descongeladas, y un aumento en las muestras con crioprotectores tras su congelación/descongelación. Esto puede explicarse si se considera que cuando las soluciones con goma xantana son congeladas y descongeladas se forman redes mucho más fuertes y cohesivas.

El estudio de la *sinéresis o exudado (Ew)* permitió observar que tanto en las muestras recién elaboradas como en las congeladas/descongeladas, los valores mayores de *Ew* se registraron en los purés con inulina añadida de forma individual, mientras que *Ew* fue menor en los purés enriquecidos solamente con aceite de oliva. Además, la capacidad de retención de agua en los purés frescos decreció con el incremento de la concentración de inulina, debido a que la gran cantidad de moléculas de inulina ocupan espacios intercatenarios que desplazan el agua.

El siguiente paso fue evaluar los cambios en las propiedades sensoriales de textura mediante la técnica del perfil realizando dicha evaluación siguiendo el proceso de consumo del puré de patata. Los trece atributos evaluados por cuatro jueces entrenados se dividieron en cuatro fases según el orden de percepción. Como resultados relevantes se pueden citar que la adición de aceite de oliva disminuye la *granulosidad visual* estando además asociada con un aumento de la *cremosidad*. Con elevadas concentraciones de aceite de oliva (0:60, 15:30 y 30:30), la *facilidad de deglución* y el *recubrimiento de paladar* fueron mayores, lo que se atribuye al hecho de que la grasa es un potenciador de la sensación de cremosidad, que produce un recubrimiento de los de tejidos bucales y, por tanto, reduce la fricción entre el alimento y los mismos. En este estudio, las principales diferencias entre las muestras con y sin aceite de oliva añadido se relacionaron con la sensación aromática y de cremosidad en boca detectada en las muestras con aceite, independientemente de la presencia o ausencia de inulina en los sistemas. Ambas *fibrosidades* (una percibida antes de ingerir el puré y otra durante la ingestión) estuvieron fuertemente correlacionadas, y se incrementaron en los purés con los contenidos más altos de inulina (60:0 y 45:15), lo que se relaciona con la presencia de grandes agregados de cristalitos del fructano. Ambas *humedades* (la primera visual y la segunda percibida en boca) también estuvieron altamente correlacionadas, y además, en todos los purés, la humedad fue mayor que en la muestra control (0:0).

Los resultados evidenciaron una *pegajosidad* significativamente mayor en las muestras recién elaboradas cuando se añadió aceite de oliva de forma individual o mezclado con concentraciones crecientes de inulina. Esto ocurre porque tanto la inulina como el aceite producen un efecto similar en la textura del puré, suavizándolo debido a que ambos ingredientes se encuentran dentro de una matriz rígida de gránulos de almidón gelatinizados. Por otro lado, se observó que la presencia de crioprotectores enmascara el efecto producido en la *cohesividad* de las muestras por la variación de las concentraciones de aceite e inulina.

Los resultados obtenidos a partir del análisis del perfil de textura sensorial permiten recomendar un enriquecimiento del puré de patata con la adición de 30 g/kg de inulina y 45 g/kg de aceite de oliva virgen extra.

Para investigar la interdependencia de los atributos se realizaron una serie de análisis de componentes principales (ACP) sobre diferentes conjuntos de datos, es decir, de forma separada sobre los datos de las muestras frescas, congeladas/descongeladas, con y sin crioprotectores, y sobre el conjunto total de los datos. Los resultados mostraron que la primera componente fue principalmente un contraste entre atributos de textura mecánicos (*pegajosidad*, *firmeza*, *cohesividad* y *adherencia*) y atributos texturales de superficie (*humedad (1)* y *humedad (2)*), tanto cuando se evaluó el conjunto total de datos, como cuando se consideraron las muestras frescas, procesadas y sin crioprotectores de forma individual. Los jueces detectaron que las muestras más adhesivas tenían una menor *humedad*, una característica bastante común en la textura de la patata. Por otro lado, la segunda componente pudo ser identificada principalmente con atributos texturales geométricos (*granulosidad*, *homogeneidad*, *fibrosidad (1)* y *fibrosidad (2)*) y residuales (*facilidad de deglución* y *recubrimiento del paladar*). Sin embargo, cuando se realizó el ACP sobre las muestras con crioprotectores de forma separada, la primera componente fue identificada en este caso con los atributos geométricos de textura detectados durante la fase de masticación y en la fase final y residual de la ingestión. Estos cambios en las correlaciones de los atributos con las componentes se debe probablemente a la reducción o ausencia de la retrogradación del almidón asociada con la congelación y descongelación del producto, que ocurre cuando la goma xantana y el kappa-carragenato no están presentes. Este hecho puede ser confirmado, dado que se observó que los purés congelados/descongelados en ausencia de crioprotectores tuvieron una *granulosidad visual* y una *fibrosidad* elevadas. De la misma manera, la *fibrosidad* percibida antes de ingerir el puré fue el atributo mejor explicado por las dos componentes principales en las muestras sin crioprotectores, y por lo tanto, el más determinante para la evaluación de su textura, mientras que en las muestras congeladas y descongeladas el atributo más idóneo para la evaluación de dichas muestras fue la *firmeza*. De estos análisis, también se derivaron otros resultados de interés: el primero fue el hecho de que se observó que existe una elevada correlación entre las dos *humedades* y las dos *fibrosidades* percibidas en distintas fases del proceso de masticación, y que por lo tanto, se puede prescindir de la evaluación tanto de la *humedad* como de la *fibrosidad* percibidas durante la ingestión del puré, sin que ello suponga una pérdida significativa de información; el segundo resultado hace referencia al nivel de concordancia del panel, éste análisis mostró que había un bajo nivel de acuerdo entre los panelistas para los atributos *pegajosidad*, *adhesividad*, *facilidad de deglución* y *recubrimiento del paladar*, lo que reflejaba que los jueces no emplearon estos atributos de la misma forma.

Efecto de la adición de mezclas de aislado de proteína de soja e inulina y del procesado en la textura de purés de patata. Aplicación de una herramienta estadística para validar las diferencias del producto y los rendimientos de un panel entrenado y otro no entrenado.

En esta parte de la tesis se estudiaron las consecuencias que la adición de mezclas de inulina (INL) y aislado de proteína de soja (SPI) tenía en las propiedades reológicas, sensoriales de textura y microestructurales de purés de patata recién elaborados y tras sufrir un proceso de congelación y descongelación.

Para la evaluación reológica de los purés de patata enriquecidos con estas mezclas, se elaboraron los productos con diez ratios diferentes de SPI:INL (0:6; 6:0; 3:3; 1,5:4,5; 4,5:1,5; 3:4,5; 4,5:3; 6:6; 6:1,5; 1,5:6), y se compararon con una muestra control sin ingredientes añadidos (0:0), estudiándose el comportamiento reológico de las muestras recién elaboradas y tras un ciclo de congelación y descongelación. Con respecto al efecto de este ciclo de congelación y descongelación, los resultados mostraron que en todos los casos el *índice de consistencia* derivado del modelo reológico de Ostwald-De Waele y la *viscosidad aparente* en 50 s^{-1} dentro de la zona pseudoplástica fueron más elevados en las muestras congeladas y descongeladas, lo que se atribuye a un posible proceso de retrogradación de la amilopectina que no es evitado ni minimizado por la adición de goma xantana, la cual sí evita la retrogradación de la amilosa y la sinéresis. Además, la presencia de ambos ingredientes funcionales en las muestras congeladas incrementó su consistencia en comparación con aquellas que sólo tenían inulina o aislado de proteína de soja. El estudio del efecto del ratio SPI:INL permite establecer que la adición de estas mezclas reduce el *índice de consistencia (k)* del producto con respecto a la muestra control elaborada sin estos ingredientes. Por otro lado, cuando la cantidad de inulina añadida fue del 6%, la adición de aislado de proteína de soja en cantidades crecientes desde el 1,5% al 6%, ocasionó una disminución de las tres propiedades reológicas determinadas (*índice de consistencia (k), viscosidad aparente en 50* s^{-1} ($\eta_{app,50}$) *y del esfuerzo de cizalla de Kokini* (σ_{oral})). Cuando se añadió inulina de forma individual, las propiedades reológicas citadas fueron mayores que cuando se añadió aislado de proteína de soja individualmente. Esto indica que la adición del aislado en una concentración mayor o igual a 4,5% causa que el sistema sea relativamente más viscoso y fluido, y menos elástico. El menor ablandamiento causado por la adición de inulina se atribuye al efecto de exclusión del almidón, lo que conduce a la formación de agregados que contienen cristales de inulina y que retienen una elevada cantidad de fase líquida incrementando la fracción de volumen. Ello justificaría que la adición de inulina refuerce la estructura de las muestras elaboradas sólo con aislado de proteína de soja.

Por otro lado, se realizó un análisis sensorial de perfil de textura (TPA) de las muestras elaboradas con los diferentes ratios de SPI:INL, evaluándose seis atributos sensoriales de textura. Esta evaluación fue realizada por dos paneles diferentes, uno entrenado compuesto por cuatro miembros (y que realizó los distintos análisis sensoriales llevados a cabo a lo largo de esta tesis), y uno no entrenado, formado por veintisiete miembros (n = 27).

El panel entrenado evaluó las mismas muestras que se analizaron reológicamente, tanto recién elaboradas como después de su procesado. Sin embargo, para la evaluación sensorial realizada por el panel no entrenado se seleccionaron tan sólo seis muestras (0:0; 0:6; 3:3; 6:0; 1,5:6; 4,5:3) que fueron previamente sometidas al proceso de congelación/descongelación. Estos ratios fueron seleccionados al objeto de garantizar una variación elevada entre las muestras evaluadas por los panelistas no entrenados y, efectivamente, diferencias muy considerables pudieron apreciarse entre las microestructuras constitutivas de estas muestras.

El estudio del efecto del ratio SPI:INL en las muestras de puré de patata reveló que en las muestras con elevadas concentraciones de aislado de proteína de soja, la presencia de este componente provocó un incremento de la *granulosidad visual*, del *recubrimiento del paladar* y de la *fibrosidad,* y una disminución de la *cremosidad* debido a la presencia de hebras del aislado. Sin embargo, en las muestras con elevadas cantidades de inulina se produjo el efecto contrario, siendo especialmente notable el incremento de la sensación de *cremosidad* percibida. Este hecho se asocia con la presencia de microcristales de inulina que ocluyen gran cantidad de agua creando una textura suave y cremosa en los purés recién elaborados. Además, en los purés congelados y descongelados en microondas, probablemente el agua acumulada en los microcristales de inulina tiende a difundirse dentro de la matriz del puré, dando lugar a una estructura más homogénea debido a la reabsorción del agua por la amilosa. Por lo tanto, previsiblemente la inulina reduce la retrogradación del almidón, facilitando asimismo la fusión del almidón retrogradado durante la descongelación.

Cuando los jueces entrenados y no entrenados fueron considerados como factores fijos, es posible evaluar el tipo de diferencias individuales existentes entre los miembros del panel, sin embargo, las conclusiones no pueden extenderse a la población a la que pertenecen estos jueces. Los resultados mostraron que los jueces entrenados tuvieron consistencia y un buen nivel de acuerdo entre ellos en la evaluación de todos los atributos, excepto en la *fibrosidad*, atributo para el que sería necesario un entrenamiento adicional. Sin embargo, cuando los jueces no entrenados se consideraron como efectos fijos, éstos mostraron falta de concordancia para todos los atributos, evidenciando así que estos jueces son en sí mismos una importante fuente de variación en las evaluaciones que realizan. Parte de esa variación puede ser debida al uso diferente que los jueces hacen de la escala, y otra parte puede atribuirse a diferencias entre panelistas tales como su desigual sensibilidad, motivación y cultura. Para obtener más conclusiones relativas a este aspecto, los jueces no entrenados se consideraron también como factores aleatorios, y los resultados mostraron que cuando la influencia de las diferencias individuales entre los jueces es eliminada, todos los atributos texturales fueron significativamente diferentes entre las muestras, e indicando que, pese a todo, este panel no entrenado no creó la suficiente varianza como para ocultar las diferencias entre las muestras evaluadas. Además, mientras que para el panel entrenado los atributos dominantes, en términos de intensidad percibida, fueron la *cremosidad* y la *consistencia*, para el panel no entrenado todos los atributos fueron percibidos de forma moderadamente intensa, lo que indica que debido al entrenamiento recibido y a la experiencia adquirida, el panel entrenado utiliza un intervalo más amplio para la percepción de cada atributo sensorial. Por otra parte, el estudio de correlación entre las puntuaciones de los atributos sensoriales evaluados por ambos paneles, permitió observar que sólo las puntuaciones otorgadas a la *cremosidad* por los dos paneles estaban correlacionadas. Por tanto, este resultado evidencia que un entrenamiento mínimo en común del significado de los diferentes descriptores de la textura entre los miembros de un panel sensorial no entrenado puede permitir obtener resultados más reproducibles. El estudio de la *aceptabilidad general* del producto realizado por los jueces no entrenados, mostró que las muestras con las concentraciones más elevadas de inulina (1,5:6 y 0:6) tuvieron la aceptabilidad mayor, debido a la suavidad y a la disminución de la sensación granulosa, ambas percibidas con el incremento de inulina. La menor granulosidad oral es el resultado de las propiedades de lubricación y recubrimiento que confieren los cristales de inulina, lo que reduce significativamente la *fibrosidad* percibida en la muestra control. Por el contrario, la aceptabilidad general del producto fue significativamente menor en las muestras enriquecidas con las mayores concentraciones de aislado de proteína de soja (3:3, 6:0 y 4,5:3).

Por último, se estudió la microestructura de las mismas seis muestras elaboradas para la evaluación sensorial llevada a cabo por el panel no entrenado. La microestructura de la muestra control reveló la existencia de una fase continua (matriz amilosa/amilopectina), mientras que en las muestras que sólo contenían inulina (ratio 0:6) se observaron los cristalitos de inulina dispersos a través de esta matriz formando un gel fuerte. La pérdida de agua consecuencia de la realización de un ciclo de congelación y descongelación, ocasionó la formación de una red compacta de cristales de inulina que se relaciona con una elevada *cremosidad* y *humedad*, y con una baja *consistencia sensorial* e *instrumental*. En la muestra con la misma cantidad de ambos ingredientes funcionales (ratio 3:3), no se observó una estructura de gel correspondiente al aislado de proteína de soja, probablemente debido al hecho de que no ocurre gelificación en esta concentración. En las muestras a las que sólo se añadió aislado de proteína de soja, se observó una red compacta formada por filamentos agregados del aislado, lo que se asocia a la baja *cremosidad* y el alto *recubrimiento del paladar* percibidos por los jueces en estas muestras. En la muestra 4,5:3 se distingue una red de filamentos del aislado sin cristales visibles de inulina que, aunque ocultos, tuvieron un efecto sinérgico en la gelificación del aislado, fortaleciendo las muestras que sólo se habían enriquecido con el aislado de proteína de soja.

Descripción y cuantificación de los atributos sensoriales de purés de patata enriquecidos con mezclas de tres ingredientes funcionales mediante paneles con diferentes grados de entrenamiento. Relación con las propiedades mecánicas.

En este último capítulo de la tesis, se evaluó la capacidad de dos paneles con distinto grado de entrenamiento para generar atributos relevantes que permitieran describir purés de patata elaborados con aceite de oliva virgen extra (EVOO), inulina (INL) y aislado de proteína de soja (SPI), mediante dos metodologías sensoriales descriptivas novedosas: Flash Profile (FP) y Projective Mapping (PM). Estos dos métodos fueron realizados por un panel semientrenado (FP) y uno no entrenado (PM), y sus resultados fueron contrastados con los obtenidos mediante un análisis descriptivo convencional (QDA) realizado por un panel entrenado. El objetivo de utilizar paneles con diferentes grados de entrenamiento fue analizar si los jueces semientrenados y no entrenados podrían generar mapas sensoriales relevantes y similares a aquellos obtenidos por un panel entrenado, con la ventaja de ahorrar tiempo y esfuerzo en dicho entrenamiento. Estos análisis se realizaron sobre una muestra de puré de patata (control) sin ingredientes añadidos y seis muestras elaboradas con los tres ingredientes mencionados, y que fueron añadidos tanto individualmente como en mezclas binarias (EVOO, SPI, INL, EVOO+INL, EVOO+SPI y INL+SPI). Sin embargo, estas técnicas descriptivas rápidas tienen el inconveniente de no permitir un análisis de varianza convencional, y por este motivo, los resultados obtenidos de cada una de las tres técnicas descriptivas se analizaron mediante tres tipos de herramientas estadísticas diferentes: Análisis de Componentes Principales (ACP), Análisis Multifactorial (AMF) y Análisis Generalizado de Procrustes (AGP).

Los perfiles sensoriales obtenidos a partir de los tres paneles, diferenciaron claramente todos los purés de aquellos elaborados con aislado de proteína de soja, tanto añadido individualmente como mezclado con aceite de oliva o inulina (1ª dimensión), estando relacionados estos últimos principalmente con una alta puntuación otorgada a los atributos de textura *granulosidad visual*, *firmeza*, *adhesividad, cohesividad*, *fibrosidad* y *recubrimiento de la boca* (por el panel entrenado), *arenoso, terroso*, *pastoso*, *recubrimiento del paladar* y *granuloso* (por el panel semientrenado), y *pastoso*, *adhesivo*, *adherente* y *recubrimiento del paladar* (por el panel no entrenado). Además, en los tres paneles las muestras enriquecidas con aislado de proteína de soja, añadida tanto de forma individual como junto a los otros dos ingredientes funcionales fueron caracterizadas por tener un olor y sabor rancio, así como sabores y aromas extraños. El resto de los purés (C, INL, EVOO e INL+EVOO) fueron posicionados a lo largo de la segunda dimensión y fueron descritos principalmente mediante atributos de color, aroma y sabor. Los análisis clusters (ACH) realizados sobre los resultados de los tres paneles, clasificaron las muestras en tres grupos. En el caso de los paneles semientrenado y no entrenado, las muestras control y aquellas enriquecidas sólo con inulina quedaron agrupadas juntas, y fueron caracterizadas por ser más cremosas, acuosas, fáciles de tragar, y con un aroma y sabor natural. Varios panelistas no entrenados incluso manifestaron una intención elevada de compra hacia el control, lo que atribuyeron a su excelente aroma y sabor. A su vez, el panel entrenado separó el puré sin ingredientes funcionales añadidos (control) del resto de purés enriquecidos, debido a su sabor a patata más intenso. En estos ACH, los grupos o clusters se separaron como consecuencia de la presencia o ausencia de aislado de proteína de soja en los productos, en respuesta a las características texturales conferidas por este ingrediente. Las muestras con aceite de oliva y con mezclas de éste con inulina fueron caracterizadas por tener un suave olor y sabor a aceite y, a su vez, una textura igualmente suave.

Los tres espacios sensoriales fueron comparados mediante un análisis multifactorial (AMF), al objeto de cuantificar la similitud general entre las configuraciones sensoriales obtenidas para las mismas muestras por los tres paneles. Los resultados de este análisis, mostraron que las dos nuevas metodologías están en bastante acuerdo con el QDA, siendo el espacio sensorial generado por el FP más similar al del QDA que aquél generado por el PM. Asimismo, se estudiaron las correlaciones existentes entre los atributos generados por los tres paneles, observándose la existencia de una alta correlación entre los atributos generados por el QDA y el FP. Por lo tanto, la definición dada por los jueces entrenados a los distintos atributos sensoriales fue bastante próxima a la percepción que los consumidores semientrenados tuvieron de los mismos. De hecho, entre los jueces de ambos paneles no se apreciaron diferencias para ninguno de los atributos equivalentes generados, siendo los más correlacionados la *adhesividad* (0,95), la *fibrosidad* (0,86), la *cremosidad* (0,95), la presencia de *colores extraños* (0,95) y la presencia de *sabores extraños* (0,89). Estos resultados sugieren que los panelistas semientrenados, y que no poseen experiencia en la evaluación sensorial de purés de patata, fueron capaces de evaluarlos de una manera muy similar a como lo hicieron los panelistas entrenados. Sin embargo, cuando se establecieron las correlaciones entre los atributos generados por los consumidores no entrenados y el panel entrenado, sí que se observó una discrepancia o falta de correlación entre los atributos *firmeza* (generado por los jueces entrenados) y *firme* (generado por los panelistas no entrenados), así como una alta correlación entre esta *firmeza* y el atributo pastoso (generado por los panelistas no entrenados). Por lo tanto, en este caso, parece que la percepción de *firmeza* no fue bien descrita por los jueces no entrenados.

Por último, y asimismo mediante análisis multifactorial (AMF), se compararon los tres espacios sensoriales de textura obtenidos a partir de las tres técnicas con los datos derivados de un perfil instrumental de textura. Los resultados mostraron que los atributos sensoriales de textura del método descriptivo convencional (QDA) estuvieron más correlacionados con las medidas instrumentales que aquellos de las otras dos técnicas sensoriales. Esto se justifica, porque los jueces entrenados, lo están de forma más específica en los parámetros texturales, y por lo tanto, estos jueces tienden a ser más detallistas respecto de los atributos sensoriales de textura, mientras que prestan una menor atención a las percepciones sensoriales de sabor y apariencia. Por el contrario, los jueces semientrenados y no entrenados se centraron más en estos últimos atributos sensoriales. La consistencia instrumental derivada del TPA estuvo altamente correlacionada con los atributos sensoriales *recubrimiento de boca* y *paladar*, *pastoso*, *densidad*, *consistencia*, *firmeza*, *fibrosidad* y *adhesividad*.

El puré elaborado con aislado de proteína de soja e inulina fue la muestra que obtuvo una correlación más baja entre los atributos sensoriales de textura y las propiedades instrumentales. Para los paneles semientrenados y de consumidores, la muestra con una mayor correlación entre medidas sensoriales e instrumentales fue aquella elaborada con aceite de oliva y aislado de proteína de soja, mientras que para el panel de jueces entrenados lo fue el puré de patata elaborado con la mezcla de aceite e inulina.

CAPÍTULO 6

CONCLUSIONES

Los resultados obtenidos en la presente Tesis Doctoral permiten extraer las conclusiones que se enumeran a continuación:

Efecto en la textura de los purés de patata de la adición de aceite de oliva virgen extra y crioprotectores.

1. La adición de aceite de oliva virgen extra o de crioprotectores al puré de patata, así como el procesado del mismo, afectaron significativamente las características físicas, estructurales y sensoriales del puré de patata. Por un lado, el incremento de la concentración de aceite de oliva originó sistemas menos estructurados y realzó el color y la luminosidad del puré de patata. Por otra parte, la adición de kappa-carragenato y goma xantana incrementó la consistencia del producto, como consecuencia del efecto de exclusión de los gránulos de almidón hinchados que promueve y favorece la gelificación del kappa-carragenato.
2. La adición de aceite de oliva en concentraciones crecientes mejora la calidad sensorial del puré de patata, reduciendo las percepciones de *granulosidad*, *densidad*, *cohesividad*, *adhesividad* y *fibrosidad*, e incrementando las de *homogeneidad*, *facilidad de deglución* y *recubrimiento del paladar* conferido por el producto.
3. Las medidas objetivas instrumentales son capaces de diferenciar las mismas variaciones o modificaciones en los atributos mecánicos de la textura de los purés apreciadas por los panelistas, mientras que por el contrario las variaciones o diferencias en los atributos geométricos de la textura del producto, tales como la *granulosidad*, la *homogeneidad* y la *fibrosidad* son más complejas, y precisan de una información de carácter estructural que facilite su interpretación.

4. Otros atributos, como la *cremosidad*, la *sensación grasa* o la *suavidad*, que dependen principalmente de la microestructura y de las propiedades superficiales del producto, contribuyen decisivamente a la sensación de textura así como a la aceptabilidad total de los purés de patata enriquecidos con aceite de oliva virgen extra, especialmente cuando se añade en una concentración de 50g/kg.

5. Por lo tanto, es posible elaborar un puré de patata enriquecido con aceite de oliva virgen extra, proporcionando al consumidor un producto con un perfil nutritivo mejorado. Además, por un lado, compensa algunos de los defectos de textura que provoca la congelación y, por otro, enriquece las características físico-químicas, funcionales y sensoriales del producto.

Efecto en la textura de los purés de patata de la adición de mezclas de inulina y aceite de oliva virgen extra.

1. Las propiedades mecánicas de la textura ponen de manifiesto que la adición de inulina y de aceite de oliva virgen extra a puré de patata, tanto de forma individual como en sus mezclas, origina un ablandamiento de la matriz rígida de amilosa/amilopectina del producto, produciéndose asimismo un efecto sinérgico entre ambos ingredientes funcionales.

2. La elaboración de un puré de patata enriquecido con 15 o 30 g/kg de inulina y 45 g/kg de aceite de oliva virgen extra es muy adecuada para lograr un incremento en la ingesta diaria tanto de fibra soluble como de ácidos grasos monoinsaturados. Ambas combinaciones de ingredientes ocasionan una importante modificación en la composición y estructura del producto, que mejora la percepción sensorial de la

textura del mismo con una granulosidad significativamente inferior a la del puré de patata control, a la vez que una aceptabilidad total superior.

3. El perfil sensorial de textura del puré de patata recién elaborado enriquecido con la misma cantidad de inulina y aceite de oliva virgen extra en la proporción 30:30 es muy similar al del puré control elaborado sin ingredientes funcionales añadidos. Este resultado es de gran utilidad práctica, dado que la industria alimentaria tiene un interés específico en la formulación de nuevos productos sin cambios en su aceptación con respecto al producto original. Por el contrario, la realización de un ciclo de congelación y descongelación, especialmente en el caso de que no se incorporen crioprotectores, lleva asociado que el perfil de textura del puré de patata enriquecido con mezclas de inulina y aceite de oliva difiera significativamente del correspondiente al del puré de patata no enriquecido, disminuyendo su calidad sensorial.

4. Los crioprotectores kappa-carragenato y goma xantana enmascaran los efectos de añadir diferentes mezclas de inulina y aceite de oliva sobre el perfil de textura de las muestras de puré de patata, lo que se atribuye a la capacidad de retención de agua conferida por la goma xantana.

5. Los análisis de componentes principales realizados individualmente sobre los datos de las muestras recién elaboradas, congeladas y descongeladas, sin crioprotectores añadidos, así como sobre el conjunto total de todos los datos, revelaron que la primera componente representó un índice del comportamiento mecánico y de la humedad del producto, mientras que cuando se realizó el análisis sobre los datos de las muestras elaboradas con crioprotectores de forma separada, la primera componente principal constituyó un índice de la aspereza/suavidad de las muestras como respuesta a la inferior retrogradación que experimenta el almidón en presencia de los hidrocoloides kappa-carragenato y goma xantana.

6. Se ha observado que existía un nivel aceptable de concordancia entre las percepciones sensoriales de textura de los panelistas que desarrollaron y evaluaron el perfil de textura. No obstante, los resultados se podrían optimizar realizando un entrenamiento más exhaustivo en el uso de las parejas de atributos sensoriales *pegajosidad* y *adhesividad*, así como en la *facilidad de deglución* y el *recubrimiento del paladar*.

7. Asimismo, se observó un solapamiento entre las puntuaciones otorgadas a las percepciones de las dos *humedades*, de la *pegajosidad* y la *adhesividad*, así como de las dos *fibrosidades* del producto, todo ello a pesar de que estos atributos sensoriales eran percibidos en distintas fases del proceso de masticación. Este resultado sugirió la posibilidad de llevar a cabo una mejora del perfil sensorial de textura desarrollado para el puré de patata, a través de una reselección de algunos de los atributos sensoriales que fueron consensuados originalmente.

Efecto de la adición de mezclas de aislado de proteína de soja e inulina y del procesado en la textura de purés de patata. Aplicación de una herramienta estadística para validar las diferencias del producto y los rendimientos de un panel entrenado y otro no entrenado.

1. A pesar de que un panel no entrenado es capaz de diferenciar las muestras de puré de patata elaboradas con diferentes cantidades de mezclas de aislado de proteína de soja e inulina, sólo para el atributo sensorial *cremosidad* se identificó una correlación lineal elevada entre las evaluaciones de este panel y las correspondientes a un panel entrenado. La percepción de *consistencia* de los panelistas entrenados estuvo bien relacionada con los parámetros reológicos que identifican el flujo del producto enriquecido con estas mezclas, reflejando estos últimos la no existencia de interacciones entre la matriz rígida de amilosa/amilopectina y las partículas de soja e inulina dispersas en esta matriz. Por lo tanto, las propiedades de flujo del producto podrían considerarse en este caso como estímulos responsables de la *consistencia* percibida sensorialmente. Sin embargo, la *consistencia* no representó por sí sola la textura del producto, y los otros cinco atributos del perfil de textura (*granulosidad visual*, *cremosidad*, *humedad*, *fibrosidad* y *recubrimiento*), que también contribuyeron decisivamente a la textura del puré, no pueden relacionarse con una sola propiedad física, si no que dependen fundamentalmente de la microestructura del producto.

2. Así, la presencia de hebras de aislado de proteína de soja fue un factor dominante en la percepción de los atributos geométricos de la textura percibidos antes y durante la ingestión del puré de patata (*granulosidad visual* y *fibrosidad*), así como en la del atributo residual *recubrimiento en boca*, mientras que la presencia de cristalitos de inulina fue la característica principal que contribuyó a la *cremosidad* del producto. Este último atributo fue percibido con mayor intensidad cuando el puré de patata se formuló añadiendo una concentración pequeña de aislado de proteína de soja (1,5%) junto con una concentración de inulina superior al 3%.

3. El comportamiento más fluido que se observó en las muestras enriquecidas con aislado de proteína de soja en concentraciones mayores o iguales a 4,5%, refleja que el gel de aislado de proteína de soja formado en la matriz del producto tenía baja capacidad de retener agua y, por lo tanto, de reducir la sinéresis del mismo.

4. Las características microestructurales y las propiedades superficiales del producto son evidentemente necesarias para comprender la parte no mecánica de la textura percibida en los purés de patata elaborados con inulina y aislado de proteína de soja, reflejando la importancia de que se estudien en el puré de patata las relaciones composición-estructura-propiedades físicas-propiedades sensoriales.

Descripción y cuantificación de los atributos sensoriales de purés de patata enriquecidos con mezclas de tres ingredientes funcionales mediante paneles con diferentes grados de entrenamiento. Relación con las propiedades mecánicas.

1. El posicionamiento relativo de las muestras de puré de patata y los atributos sensoriales generados mediante análisis descriptivo cuantitativo, *flash profile* y *projective mapping*, evidenció que los espacios sensoriales obtenidos por las tres técnicas podían considerarse lo suficientemente similares, aunque un análisis más exhaustivo deja entrever interesantes diferencias entre ellos. Los resultados mostraron que existe una oposición entre muestras a lo largo de la primera dimensión, y que fue dependiente de la presencia o ausencia de aislado de proteína de soja en la formulación; así las muestras elaboradas con soja, añadida tanto de forma individual como mezclada con aceite o inulina, se separaron del resto como consecuencia de los atributos sensoriales de textura percibidos en los purés. Sin embargo, el posicionamiento de las muestras de puré a lo largo de la segunda dimensión fue más dependiente de otras percepciones sensoriales, tales como el color, su aroma y el sabor.
2. Asimismo, con las tres metodologías sensoriales utilizadas, los análisis de *clusters* agruparon las muestras de puré en tres grupos distintos. Sin embargo, mientras que en el análisis descriptivo cuantitativo el *cluster 1* sólo agrupó a la muestra

control sin ingredientes funcionales añadidos, en las dos metodologías más innovadoras la muestra control fue agrupada junto con aquella elaborada con inulina, en respuesta a las distintas percepciones sensoriales relacionadas con la apariencia y el sabor.

3. A su vez, los resultados obtenidos mediante análisis multifactorial mostraron que existe una adecuada correlación entre el análisis descriptivo cuantitativo (*QDA*) y las dos nuevas metodologías ensayadas; no obstante, el espacio sensorial derivado del *flash profile* fue más similar al del *QDA* que el espacio sensorial derivado utilizando la metodología *projective mapping*.

4. Los atributos sensoriales de textura evaluados por los paneles entrenado (*QDA*) y semientrenado (*flash profile*) mostraron elevadas correlaciones, indicando que aunque los jueces semientrenados no tenían experiencia en la descripción de la textura del puré de patata, eran capaces de evaluarla y percibirla de forma similar a como lo hicieron los jueces entrenados. Sin embargo, la percepción sensorial de la *firmeza* de los jueces no entrenados (*projective mapping*), no estaba en correlacionada con la percepción que tuvo el panel entrenado de este atributo de la textura. Esto sugiere la necesidad de investigar las percepciones de los consumidores para favorecer la optimización de la calidad sensorial de nuevos productos.

5. Del mismo modo, los parámetros instrumentales de textura mostraron una correlación más baja con las percepciones sensoriales de la textura generadas a través del *projective mapping*. Este resultado evidencia que se desconoce tanto el significado real de los atributos de textura generados por los jueces semientrenados y no entrenados, así como la forma en la que son medidos, siendo por lo tanto interesante y aconsejable obtener información y entender cómo perciben y describen los consumidores las diferencias entre los purés de patata.

6. Finalmente, se observaron diferencias en los atributos organolépticos utilizados por los tres paneles para la descripción de las diferencias entre muestras de puré. La distribución de atributos de acuerdo al empleo de los diferentes sentidos fue globalmente bastante similar para las dos nuevas metodologías. Sin embargo, los jueces entrenados generaron un porcentaje superior de atributos sensoriales de textura que de apariencia y sabor, y no generaron atributos asociados con el olor. Por el contrario, los atributos de textura no fueron tan relevantes para los consumidores, quienes prestaron mayor atención a las percepciones sensoriales del aroma y la apariencia.