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CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

INSTITUTO DE AGROQUÍMICA Y TECNOLOGÍA DE ALIMENTOS

INFLUENCIA DE LA ADICIÓN DE UN INGREDIENTE FUNCIONAL EN LA CALIDAD DE UN PRODUCTO DE BOLLERÍA. ASPECTOS REOLÓGICOS Y TEXTURALES Y SU RELACIÓN CON LA ACEPTACIÓN SENSORIAL

Tesis Doctoral

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HACEN CONSTAR QUE:

el trabajo de investigación titulado "INFLUENCIA DE LA ADICIÓN DE UN INGREDIENTE FUNCIONAL EN LA CALIDAD DE UN PRODUCTO DE BOLLERÍA. ASPECTOS REOLÓGICOS Y TEXTURALES Y SU RELACIÓN CON LA ACEPTACIÓN SENSORIAL" que presenta Dña. Raquel Baixauli Muñoz por la Universidad Politécnica de Valencia, ha sido realizado en el Instituto de Agroquímica y Tecnología de alimentos (IATA-CSIC) bajo nuestra dirección y que reúne las condiciones para optar al grado de Doctor.

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Fdo: Dra. Susana Fiszman Dal Santo

Fdo: Dra. Ana Salvador Alcaraz

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RESUMEN

INFLUENCIA DE LA ADICIÓN DE UN INGREDIENTE FUNCIONAL EN LA CALIDAD DE UN PRODUCTO DE BOLLERÍA. ASPECTOS REOLÓGICOS Y TEXTURALES Y SU RELACIÓN CON LA ACEPTACIÓN SENSORIAL

En este trabajo de tesis se estudió el efecto de la adición de una fibra funcional, almidón resistente, en un producto de bollería tradicional (magdalena) sobre las propiedades tanto reológicas de la masa cruda como texturales del producto final, y su relación con la aceptación sensorial de los consumidores. Hoy en día la fibra continúa siendo uno de los temas más discutidos en alimentación y nutrición. A pesar de los esfuerzos de los nutricionistas, la dieta de una persona occidental no llega a las dosis recomendadas (25 a 30g/día) de fibra en los alimentos que ingiere. En parte esta situación se atribuye a la falta de atractivo de los alimentos ricos en fibra, que generalmente se asocian a un sabor fuerte, falta de palatabilidad, una textura grosera y sensación de sequedad bucal.

La formulación de una magdalena tradicional consta básicamente de harina, azúcar, huevos, leche y aceite. Todos estos ingredientes contribuyen en mayor o menor medida a la calidad sensorial a la que el consumidor está habituado. Conocer las interacciones que un nuevo ingrediente pueda desarrollar con los constituyentes básicos es fundamental para predecir los cambios que se detectarán en las características del producto final o para replantear el proceso de elaboración y cocción.

Se investigó si la forma de dosificar la pasta en los moldes de magdalena afectaría al producto final. Los resultados revelaron que aunque se

encontraron diferencias microestructurales y reológicas, estos cambios no afectaron a las propiedades del producto final.

Se estudiaron las características reológicas dinámicas de la masa cruda y cómo variaban con la adición de almidón resistente. Esto permitió observar que la viscosidad de la masa diminuía con la adición de almidón resistente, lo cual no es favorable para el desarrollo del producto final. El estudio de las propiedades reológicas reveló que durante el calentamiento, al aumentar la adición de almidón resistente, disminuían las propiedades elásticas de la pasta.

Se estudió la textura de las magdalenas, con la adición de almidón resistente y su evolución durante el almacenamiento. Al aumentar la concentración de almidón resistente la dureza de las magdalenas disminuyó, y la elasticidad, cohesividad y resilencia disminuyeron a partir de concentraciones elevadas de almidón resistente. Durante el almacenamiento las magdalenas con almidón resistente permanecieron más tiernas, siendo este efecto más evidente a elevadas concentraciones. Un análisis de supervivencia para estimar la vida útil sensorial de magdalenas confirmó estos resultados.

Se generaron los descriptores que mejor definían las características sensoriales más representativas de este tipo de producto de bollería cuando se adicionaba almidón resistente. Se entrenó un panel de diez jueces en la evaluación de dichos descriptores. Se realizó un analisis descriptivo de las muestras, apareciendo “arenosidad” como nuevo parámetro. Se evaluó la aceptabilidad sensorial de las distintas magdalenas mediante un estudio de consumidores, y no se encontraron diferencias significativas entre las magdalenas con distintas concentraciones de almidón resistente.

Finalmente, se analizó si el efecto de conocer la información nutricional podría influir en la opinión de los consumidores sobre la aceptabilidad de este tipo de magdalenas, la adición de almidón resistente no tuvo mucha influencia ya que los consumidores parecían no terminar de "creer" que se trataba de una magdalena con fibra, ya que su aspecto era similar al de una magdalena tradicional.

RESUM

INFLUÈNCIA DE L'ADDICIÓ D'UN INGREDIENT FUNCIONAL EN LA QUALITAT D'UN PRODUCTE DE BRIOXERIA. ASPECTES REOLÒGICS I TEXTURALS I LA SEUA RELACIÓ AMB L'ACCEPTACIÓ SENSORIAL

En aquest treball de tesi es va estudiar l'efecte de l'addició d'una fibra funcional, midó resistent, en un producte de brioxeria tradicional (magdalena) sobre les propietats tant reològiques de la massa crua com texturals del producte final, i la seua relació amb l'acceptació sensorial dels consumidors. Hui en dia la fibra continua sent un dels temes més discutits en alimentació i nutrició. A pesar dels esforços dels nutricionistes, la dieta d'una persona occidental no arriba a les dosis recomanades (25 a 30g/dia) de fibra en els aliments que ingerix. En part aquesta situació s'atribuïx a la a la falta d'atractiu dels aliments rics en fibra, que generalment s'associen a un sabor fort, falta de palatabilitat, una textura grossera i sensació de sequedat bucal.

La formulació d'una magdalena tradicional consta bàsicament de farina, sucre, ous, llet i oli. Totsingredients contribuïxen en major o menor mesura a la qualitat sensorial a la qual el consumidor està habituat. Conéixer les interaccions que un nou ingredient puga desenvolupar amb els constituents bàsics és fonamental per a predir els canvis que es detectaren en les característiques del producte final o per a replantejar el procés d'elaboració i cocció.

Es va investigar si la forma de dosificar la pasta en els motles de magdalena afectaria el producte final. Els resultats van revelar que encara

que es van trobar diferències microestructurals i reològiques, estos canvis no van afectar les propietats del producte final.

Es van estudiar les característiques reològiques dinàmiques de la massa crua i com variaven amb l'addició de midó resistent. Açò va permetre observar que la viscositat de la massa disminuïa amb l'addició de midó resistent, la qual cosa no és favorable per al desenvolupament del producte final. L'estudi de les propietats reológiques va revelar que durant el calfament, a l'augmentar l'addició de midó resistent, disminuïen les propietats elàstiques de la pasta.

Es va estudiar la textura de les magdalenes, amb l'addició de midó resistent i la seua evolució durant l'emmagatzemament. A l'augmentar la concentració de midó resistent la duresa de les magdalenes va disminuir, i l'elasticitat, cohesivitat i resilencia van disminuir a partir de concentracions elevades de midó resistent. Durant l'emmagatzemament les magdalenes amb midó resistent van romandre més tendres, sent este efecte més evident a elevades concentracions. Una anàlisi de supervivència per a estimar la vida útil sensorial de magdalenes va confirmar estos resultats.

Es van generar els descriptors que millor definien les característiques sensorials més representatives d'este tipus de producte de brioxeria quan s'addicionava midó resistent. Es va entrenar un panell de deu jutges en l'avaluació de dites descriptores. Es va realitzar un anàlisi descriptiva de les mostres, apareixent "arenositat" com nou paràmetre. Es va avaluar l'acceptabilitat sensorial de les distintes magdalenes per mitjà d'un estudi de consumidors, i no es van trobar diferències significatives entre les magdalenes amb distintes concentracions de midó resistent.

Finalment, es va analitzar si l'efecte de conéixer la informació nutricional podria influir en l'opinió dels consumidors sobre l'acceptabilitat d'este tipus de magdalenes, l'addició de midó resistent no va tindre molta influència ja que els consumidors pareixien no acabar de “creure” que es tractava d'una magdalena amb fibra, ja que el seu aspecte era semblant al d'una magdalena tradicional.

SUMMARY

INFLUENCE OF THE ADDITION OF A FUNCTIONAL INGREDIENT ON THE QUALITY OF A BAKERY PRODUCT. RHEOLOGICAL AND TEXTURAL ASPECTS AND ITS RELATION TO THE SENSORY ACCEPTABILITY

In this thesis work the addition of a functional fibre, resistant starch, was studied in a traditional bakery product (magdalena). The effect on both the properties rheological of the raw batter as well as the textural ones on the final bakery product, and its relation to the consumer acceptability was evaluated. Nowadays, fibre is one of the most discussed subjects on food and nutrition. In spite of the nutritionist's efforts, western people diet is below the fibre recommended daily intake (25-30g/day). In part this situation is due to the lack of attractive of the food high in fibre, usually associated to a strong flavour, absence of palatability, coarse texture and a dryness oral sensation.

A traditional muffin formulation is composed of flour, sugar, eggs, milk and oil. All these ingredients have different contributions to the sensory quality that the consumer is accustomed to. It is crucial to know the interactions that a new ingredient could develop with the basic constituents to predict the changes that would take place on the final bakery product characteristics or to reconsider the elaboration and baking process.

It was investigated whether the way of dosing the dough had any effect on the final product. The results showed that although there were found

microstructural and rheological differences, these changes did not affect the characteristics of the final baked product.

The dynamic rheological properties of the raw batter and how these properties changed with the addition of resistant starch were studied. This allowed to observe that the batter viscosity decreased with the addition of resistant starch, which was not favourable to the development of the final baked product. The study of the rheological properties revealed that during the heating process, when the addition of resistant starch increased, the elastic properties of the batter diminished.

The texture of the muffins with the addition of resistant starch and its evolution during the storage were studied. When the concentration of resistant starch increase the hardness of muffins decreased, and at high concentrations of resistant starch the springiness, cohesiveness and resilience decreased. During the storage time muffins with resistant starch stayed softer than the control ones, this effect was evident at high concentrations. Survival analysis methodology to estimate sensory shelf-life of muffins confirmed these results.

A selection of descriptors was made to define the sensory properties of a bakery product when resistant starch was added. A sensory panel of ten assessors was trained in the evaluation of these descriptors. A descriptive analysis was performed, grittiness appear as a new feature. Sensory acceptability of the muffins was evaluated with a consumers study, there were not significant differences between muffins with different resistant starch concentrations.

Finally, it was studied whether the effect of knowing the nutritional information could affect the consumers opinion about the acceptability of the muffins, the addition of resistant starch did not have much influence, because it seemed that they acted as though they ‘cannot quite believe’ that it was a muffin with fibre, because its appearance was similar to a traditional one.

ÍNDICE

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INTRODUCCIÓN

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Productos de bollería

Se entiende como producto de bollería aquel cuya masa está compuesta por una base de harina que incorpora grasa y azúcar como elementos principales y como opcionales huevos, leche y otros componentes. Un aspecto importante de los productos de bollería aparte de su dulzor, es su textura blanda y su palatabilidad asociada al cierto contenido graso que favorece la facilidad de masticación, aspecto valorado positivamente por los consumidores. En la Tabla 1 se muestra una clasificación de este tipo de productos basados en las características tecnológicas y en el tipo de cocción.

Tabla1. Tipos de productos de bollería y ejemplos

	Tipo de cocción	**Estructura interna**	**Levadura**	**Productos**
BOLLERIA	HORNEADA	HOJALDRADA	Biológica	*Croissants*
				Ensaimadas
			Química	*Hojaldres*
		REGULAR	Biológica	*Brioches*
			Química	*Magdalenas*
				Bizcochos
	FRITA	REGULAR	Biológica	*Doughnuts*
			Sin levadura	*Buñuelos de viento*
				Churros

Hábitos de consumo

Los productos de bollería forman parte de los hábitos de alimentación. Desde el punto de vista nutricional la bollería generalmente no está bien considerada, ya que está constituida por productos de alto contenido calórico. En la Figura 1 se puede observar las cantidades consumidas en España por habitante y año, de estos productos junto con galletas y productos de pastelería durante los últimos veinte años.

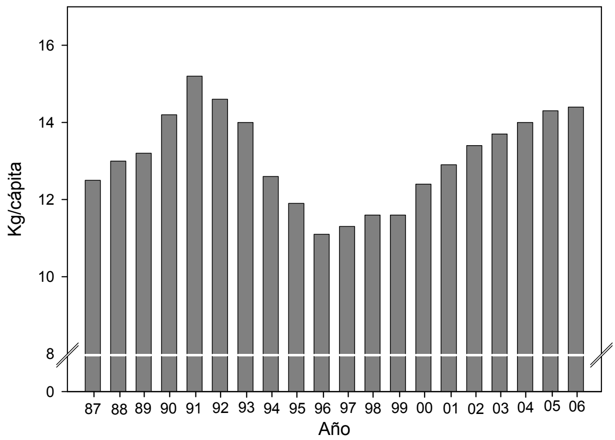

Figura 1. Evolución del consumo de galletas, bollería y pastelería (MAPA, 2006)

Como se puede observar, la evolución del consumo ha aumentado en los últimos diez años; este aumento puede deberse a cambios socioeconómicos, en el estilo de vida o en la dieta. Se ha incrementado la alimentación fuera del hogar, así como las comidas rápidas o los precocinados y es en este contexto en el que se sitúa el consumo de bollería (Quílez y Rafecas, 2002). La categoría más demandada por el consumidor español continua siendo la bollería de desayuno, en la que se encuentran productos tradicionales como los "sobaos", el "pan de leche", los "brioches" y las "magdalenas", entre otros. Éstas últimas son el producto líder por excelencia, representando el 53% de las ventas totales de los productos de desayuno

Funcionalidad de los ingredientes de un producto de bollería

Explicar la funcionalidad específica de cada uno de lo ingredientes es una tarea difícil, ya que se trata de una matriz bastante compleja. Cada ingrediente contribuye en un aspecto particular a la calidad del producto: estructura, humedad, sabor, etc. Cualquier cambio en algún ingrediente, su cantidad o cualquier cambio en la forma de fabricar el producto de bollería puede afectar al producto final. Muchos ingredientes interactúan entre sí y pueden afectar a la textura del producto.

Harina de trigo

La harina de trigo es la base en la formulación de los productos de bollería. Es la que proporciona estructura, textura y sabor a los productos. La harina tiene un determinado contenido en almidón y proteínas (glutenina, gliadina, globulina y albúmina) que le otorgan su funcionalidad.

El almidón es uno de los componentes de la harina que fortalecen el producto horneado mediante la gelatinización, y también es uno de los responsables de la formación de la miga. La miga se crea durante el horneado y depende del número y tamaño de celdas de gas que se forman, del grado de gelatinización del almidón y el grado de desnaturalización de proteinas (Jacobson, 1997).

Cuando se mezclan con el agua, las proteínas de la harina forman una masa viscoelástica que se denomina gluten. La formación del gluten depende de tres factores: la presencia de proteínas en la harina, la hidratación de las mismas debido a la adición de agua y la aportación de energía durante el batido. La glutenina contribuye a la extensibilidad de la masa, mientras que la gliadina contribuye a la elasticidad y cohesividad. La habilidad del gluten de expandirse, debido a la presión interna de los gases tales como aire, vapor o dióxido de carbono, se combina con la elasticidad de la glutenina y la fluidez de la gliadina (Conforti, 2006).

En productos tipo masa batida, la calidad del gluten no es muy importante, ya que no se forma en las primeras etapas del mezclado; debido a que la baja viscosidad del sistema hace que no se transfiera la suficiente energía y, por lo tanto, se dificulta la formación del gluten (Cauvain y Young, 2001). Por lo tanto, un tipo apropiado de harina en este tipo de productos es una harina floja, baja en contenido en gluten, con un contenido en proteínas del 8% aproximadamente, de gluten extensible y poco tenaz, lo cual le dará al producto de bollería una estructura más esponjosa.

El almidón también desempeña un papel importante en la formación de la estructura del producto de bollería, ya que determina la viscosidad de la masa durante el calentamiento ayudando a retener los gases que se expanden, el dióxido de carbono (del impulsor), el aire (que se atrapa durante el batido) y vapor (del agua añadida).

Azúcar

El azúcar es el edulcorante más usado en productos de bollería. Aparte de contribuir en el dulzor, el azúcar tiene efecto sobre el volumen, humedad, terneza, color, apariencia y naturalmente sobre el contenido calórico de los productos de bollería.

El aporte de dulzor es la principal función que se espera de los azúcares que se añaden a las masas batidas. El azúcar, junto con otros ingredientes ayuda al desarrollo del producto en el horno (Tejero, 2000), es decir, en la retención de las burbujas de aire en el sistema y prolonga el periodo de su expansión lo que contribuye a un aumento del volumen del producto. Durante el proceso de horneado el azúcar aumenta la temperatura a la cual tiene lugar la gelatinización del almidón, lo cual también eleva la temperatura de desnaturalización de las proteínas, dando al gluten más tiempo para desarrollarse; de este modo se produce un mayor aumento de volumen del producto horneado (Conforti y Strait, 1999; Conforti, 2006). Dependiendo de la concentración de azúcar, ésta puede competir por el por el agua disponible y necesaria para la hidratación de las proteínas y el almidón, y eventualmente en el desarrollo del gluten. La naturaleza higroscópica y de retención de agua del azúcar aumenta la humedad en este tipo de productos, lo cual puede favorecer un aumento de la vida del producto, ya que esta propiedad contribuye a la pérdida de humedad durante el almacenamiento (Lahtinen et al., 1998; Conforti, 2006). Otro efecto que aporta el azúcar es el dorado de la corteza por medio de la reacción de Maillard.

Grasas

En los productos de bollería se puede emplear como grasa aceites vegetales, grasas fluidas (parcialmente hidrogenadas), manteca o mantequilla. La grasa ayuda a incorporar aire durante el mezclado de la masa, las burbujas de aire que quedan atrapadas acumulan vapor de agua y el gas que aporta el impulsor se expande durante el horneado. Esto permite una distribución uniforme de los gases del impulsor y del vapor de agua que se forma durante el horneado, lo que contribuye a un buen volumen final. La incorporación de grasas en la fórmula proporciona una textura tierna, húmeda y suave y disminuye el desmenuzamiento de la miga, proporcionándole también un sabor característico (Stauffer, 1998; Lai y Lin, 2006; Oreopoulou, 2006).

Impulsores

El impulsor estará formado por un ácido y por un dador de CO_2. El más empleado es el bicarbonato sódico, éste reacciona con un ácido para una correcta producción de anhídrido carbónico. Entre los ácidos que se pueden utilizar están el ácido acético, cítrico, tartárico o mezcla de láctico y acético. La elección correcta del ácido se basa en los valores de neutralización y equivalencia. El valor de neutralización indica los gramos de bicarbonato sódico que se neutralizan por cada cien gramos de ácido. El valor de equivalencia es el número de gramos de ácido que tienen que usarse para neutralizar un gramo de bicarbonato sódico. También es importante la velocidad de reacción. Los impulsores o levaduras químicas son los responsables directos del aumento de volumen que se produce en el horneado del producto. Los gases que producen aumentan su volumen con el calor y se expanden hinchando los productos. El impulsor empleado debe de ser lo suficientemente rápido para que dé el suficiente impulso antes de que se forme la estructura (cuando el almidón gelatiniza), pero no demasiado rápido, porque podrían producirse túneles cuando el gas se escapa en la primera etapa del proceso de horneado, que es cuando la viscosidad de la masa todavía es baja. En el caso concreto de las magdalenas, si lo que interesa es obtener un pico o copete es importante que la producción de gas sea en las últimas fases del horneado, en el momento en que las partes externas han colapsado la estructura y el incremento de volumen se produce principalmente en la parte central; en este caso se utilizaran impulsores de acción lenta (Gómez y Ronda, 2002).

Leche

La fase líquida es un componente esencial en los productos de bollería. La cantidad de agua que se aporta a la masa tiene influencia sobre la calidad, textura, sabor, olor y volumen de los productos de bollería. El agua no se añade como ingrediente, sino que está presente a través de otros ingredientes como la leche (Chiech, 2006). La leche hidrata el almidón de la harina, y los gránulos hinchados cuando se calientan, gelatinizan. La leche además disuelve ingredientes tales como el azúcar, durante el batido y el horneado. También es importante porque libera el dióxido de carbono del impulsor. La leche además de ser importante por su aporte de agua, confiere también un sabor característico y nutrientes (calcio, vitamina B) y contiene una cierta cantidad de componentes que ayudan a que se produzca el dorado de la corteza, ya que la lactosa y las proteínas de la leche participan en la reacción de Maillard.

Huevo

La incorporación de huevo en los productos de bollería no sólo aumenta el valor nutricional del producto sino que aporta interesantes propiedades funcionales, además de aportar mejor color y apariencia al producto final. Entre las propiedades que aporta el huevo están: (a) aumentar la humedad, (b) facilitar la incorporación aire, debido a la capacidad de sus proteínas de formar espuma cuando se bate, (c) atrapar una gran cantidad de aire, (d) enriquecer, ya que en la yema hay una alta proporción de grasa, (e) emulsionar, debido a la presencia de lecitina en la yema, y (f) estructurar, debido a la presencia de las proteínas que se encuentran tanto en la clara como en la yema y que coagulan durante el calentamiento (Conforti, 2006).

La clara de huevo consiste en una mezcla compleja de proteínas tales como albúmina y globulinas, estas proteínas son las más importantes para producir un aumento de volumen en los productos de bollería. Las proteínas de la clara son capaces de mejorar la dispersión del aire que se encuentra en la masa antes de ser horneada y estabiliza la uniformidad de tamaño de las celdas de aire durante el horneado, la coagulación de estas proteínas estabiliza el volumen del producto final (Arunepanlop et al., 1996; Çelik et al., 2007). Cuando se bate la clara de huevo, se incorporan burbujas de aire en la masa. El azúcar se añade cuando se ha formado la espuma de clara (clara a punto de nieve), ya que la estabiliza.

La yema es más valiosa como alimento que la clara, ya que contiene minerales y vitaminas. La grasa que aporta la yema actúa como emulsionante, debido a su contenido en fosfolípidos (lecitinas y cefalinas), y contribuye a la textura. La yema permite obtener una buena miga, permitiendo mayor emulsión al aumentar el volumen de la masa batida, lo que repercutirá en un mayor esponjamiento (Kamat et al., 1973).

Otros ingredientes

En los últimos años, los consumidores están mejor informados sobre la relación existente entre dieta y salud; por lo tanto ha aumentado la demanda de alimentos que ofrezcan alta calidad, seguridad, menos grasa, colesterol, azúcar y sodio, y menos calorías que antes. La industria alimentaria intenta responder a las demandas de los consumidores desarrollando nuevos productos "saludables", bajando el nivel de grasas o azúcar, añadiendo fibra, etc. Las formulaciones de productos de bollería permiten la inclusión de nuevos ingredientes intentando no modificar sustancialmente las propiedades organolépticas y de textura de estos productos.

Sustitutos del azúcar (edulcorantes)

Los diabéticos y aquellos consumidores preocupados por su salud han promovido la aparición de productos de bollería sin azúcar.

Se emplean mezclas de azúcar con sustitutos del azúcar (fructosa, sorbitol y xilitol) o bien edulcorantes artificiales (acesulfame K, aspartamo y sacarina). Uno de los inconvenientes de su empleo es que no aportan las características funcionales del azúcar (volumen o textura). Hicsasmaz, Yazgan, Bozogu y Kaunas (2003) obtuvieron un producto muy similar a un bizcocho (high-ratio cake) con respecto a las características de las masas, porosidad y tamaño y distribución de las celdas cuando se sustituía un 25% del azúcar por polidextrosa, aunque la expansión de las burbujas de la masa disminuía a medida que la cantidad de azúcar disminuía, lo cual significaba una disminución del volumen del bizcocho. Nelson (2000) estudió que los edulcorantes solo proporcionaban dulzor. Para lograr que estos productos tengan las propiedades funcionales que les aportaría el azúcar se pueden combinar con productos que aumenten el volumen como maltodextrina y gomas alimentarias. Se pueden obtener bizcochos (layer cake) bajos en calorías de una calidad aceptable a través de masas en las cuales se ha sustituido parcialmente el azúcar por sorbitol o polidextrosa si se selecciona un tipo y nivel adecuado de emulsionante (Kamel y Rasper, 1988).

Sustitutos de la grasa

Un menor contenido en grasa salvaguarda la salud de ciertos riesgos tales como enfermedades cardiovasculares, arterosclerosis, diabetes y obesidad. Sin embargo, se pretende no sacrificar las características funcionales típicas de las grasas.

Entre los ingredientes existentes para sustituir la grasa se encuentran los almidones modificados, maltodextrinas, fibras, gomas, emulsionantes, y sustitutos basados en proteínas. Cuando la grasa se elimina totalmente de la formulación, el volumen disminuye, la miga es menos tierna y la estructura se vuelve irregular. Los sustitutos de grasa suplen alguna de sus propiedades funcionales. Desafortunadamente, la mayoría de estos sustitutos no pueden recrear por completo las propiedades funcionales y sensoriales de las grasas. Pong et al. (1991) estudiaron la sustitución de la grasa por un sustituto comercial (N-Flate) (mezca de mono y diglicéridos y monoester de poliglicerol con almidón de maiz waxy pregelatinizado y goma guar). Encontraron que la altura del bizcocho (cupcake) disminuía, aumentaba la firmeza, el contenido en humedad aumentaba, el color de la miga era más oscuro y sensorialmente el bizcocho era menos tierno y tenía menos uniformidad de celdas. Posibles enfoques de la sustitución de grasas son los carbohidratos, proteínas o ingredientes basados en algunos lípidos, bien individualmente o combinados (Akoh, 1998).

Fibras

El concepto de fibra ha ido evolucionando a lo largo del tiempo. En 2001, la AACC (American Association of Cereal Chemists) adoptó la siguiente definición: "La fibra dietética es la parte comestible de las plantas o carbohidratos análogos, resistentes a la digestión o absorción en el intestino delgado humano, con fermentación parcial o total en el intestino grueso. La fibra dietética incluye polisacáridos, oligosacáridos, lignina y sustancias asociadas. La fibra dietética promueve efectos fisiológicos beneficiosos, incluyendo laxación y/o disminución de la glucosa en sangre". En 2002 el FNB (Food and Nutrition Borrad of the Nacional Academy of Sciences, USA) definió la fibra dietética de la siguiente forma: "La fibra dietética consiste en carbohidratos no digestibles y lignina intrínsecos e intactos en las plantas. La fibra funcional consiste en carbohidratos no digestibles aislados y lignina que tienen efectos fisiológicos beneficiosos en humanos. La fibra total es la suma de la fibra dietética y la fibra funcional" Estas definiciones nuevas incluyen oligosacáridos, almidón resistente y lignina en la fibra dietética y fibra total. Además, ambas definiciones requieren que los compuestos incluidos no sólo sean indigestibles en el intestino delgado, sino que tengan efectos fisiológicos beneficiosos típicos de la fibra dietética (Asp, 2004).

El consumo de fibra en España está por debajo de las recomendaciones dietéticas con una ingesta de 18 g/día frente a los 30 g/día recomendados. Una solución a esta deficiencia de ingesta de fibra sería aumentando el consumo de alimentos con un alto contenido en fibra. El problema es que las costumbres sobre la dieta son difíciles de cambiar, ya que la pauta de selección del consumo de alimentos está dominada por las preferencias sensoriales en sabores y texturas (Fondroy et al, 1989). Por esta razón la incorporación de fibra a los productos de bollería intentando no sacrificar las propiedades sensoriales es un tema de estudio muy interesante.

La forma más sencilla de aumentar la cantidad de fibra en productos horneados es utilizar harina integral, pero uno de los inconvenientes que presenta cuando se incorpora harina integral es que su aceptación sensorial es baja. Se están empleando en numerosos productos fuentes de fibra soluble como el salvado de avena. Sin embargo, la cantidad de salvado de avena que se emplea en productos horneados es bajo, posiblemente porque el salvado afecta negativamente a la textura del producto cuando éste se compara con las formulaciones originales (Hudson et al., 1992). Se han empleado otros tipos de fibra para incrementar la cantidad de fibra dietética en productos de bollería como bizcochos o magdalenas. Por ejemplo, se ha añadido fibra dietética de melocotón a magdalenas; éstas eran más húmedas y más oscuras que las magdalenas control (sin fibra), y algunos parámetros de textura cambiaron negativamente (dureza, masticabilidad) (Grigelmo-Miguel et al., 1999). Polizzoto et al. (1983) y Shafer y Zabik (1978) estudiaron el efecto de diferentes fuentes de fibra (α-celulosa, salvado de maíz, salvado de arroz, salvado de soja, salvado de trigo y salvado de avena) en magdalenas y bizcochos (layer cake) respectivamente, siendo las magdalenas con salvado de maíz y con salvado de trigo las únicas aceptables para los consumidores, los bizcochos hechos con salvado de soja y salvado de avena no fueron aceptados debido a la baja puntuación en sabor que otorgaron los consumidores.

Un tipo de producto con propiedades equivalentes a la fibra son los almidones resistentes.

Almidón Resistente

El almidón es una de las formas principales de los carbohidratos. Los almidones se pueden clasificar según sus características nutricionales en almidones digestibles y almidones resistentes. Los almidones digestibles, a su vez se subclasifican en "lentamente digestibles" y "rápidamente digestibles". Un ejemplo de estos últimos, sería el puré de patatas u otros alimentos amiláceos recientemente cocidos, que se digieren rápidamente en el intestino delgado; esto se debe a que los gránulos de almidón se han gelatinizado durante la cocción, y son susceptibles de ataque enzimático. Los "lentamente digestibles" se degradan más lentamente pero la digestión es completa en el intestino delgado, como por ejemplo los cereales crudos. Sin embargo, los investigadores coinciden en que la tasa de hidrólisis de un almidón a compuestos de bajo peso molecular, tanto *in vivo* como *in vitro*, depende del origen del almidón y de las condiciones de procesamiento (Ciacco et al., 2001). Por último, los almidones resistentes (AR) no se hidrolizan en esta etapa de la digestión humana. Los enzimas digestivos no son capaces de penetrar el polímero lineal de amilosa que se encuentra en este tipo de almidón con alto contenido en amilosa.

El concepto de AR, introducido por Englyst et al., en 1982, ha evolucionado durante las dos últimas décadas y es un concepto aún en continuo desarrollo. Ha sido definido como "la fracción del almidón que resiste la hidrólisis enzimática" (Berry, 1986) y actualmente se define como "almidón y productos de degradación del almidón que no se absorben en el intestino delgado de individuos sanos" (Asp et al., 1992). Esta definición de carácter fisiológico hace que su análisis necesite acomodarse a un intervalo amplio de circunstancias que afectan la digestibilidad del almidón y hace difícil disponer de un método *in vitro* que lo simule.

Actualmente, determinados tipos de AR se encuentran disponibles como ingredientes comerciales.

El AR ha sido clasificado en función de su origen y de sus características físicas en cuatro tipos (Tabla 2).

Tabla 2. Clasificación de los almidones resistentes (Extraida de: Topping et al., 2003)

Tipo de almidón resistente (AR)	Descripción	Origen
AR1	Almidón fisicamente retenido en una matriz alimenticia	Granos, semillas, cereales enteros o parcialmente molidos
AR2	Almidón nativo granular	Patata cruda, plátanos verdes, almidones de alta amilosa
AR3	Almidón retrogradado o cristalino	Pan, patatas cocidas y enfriadas
AR4	Almidón químicamente modificado	Éteres, almidones esterificados, entrecruzados (por ej. acetatos)

El AR1 es el AR que es resistente porque está en una forma físicamente inaccesible para la digestión, debido a la presencia de pared celular intacta en granos, semillas o tubérculos; el AR1 es estable al calentamiento en la mayoría de los procesos de cocinado y permite su uso como ingrediente en una amplia variedad de alimentos, se hace menos resistente a la digestión con la molienda y con la masticación. El AR2 es un almidón nativo granular que se protege de la digestión por la conformación o estructura del granulo de almidón presente, por ejemplo, en patata cruda y plátanos verdes: hay un caso particular de AR2 que es único ya que conserva su estructura y resistencia incluso durante el procesado y preparación de muchos alimentos, este AR2 se denomina almidón de maíz de alto contenido en amilosa. El AR3 representa la fracción de almidón más resistente y se forma durante la retrogradación de los gránulos de almidón; el AR3 se hace menos resistente a la digestión por las condiciones de procesado de los alimentos, por ejemplo, durante la preparación de pan. El AR4 se trata de un grupo de almidones que se han modificado químicamente; como resultado de su modificacion quimica, puede resistir la hidrólisis después del procesado de los alimentos, aunque esto dependerá del tipo de almidón base, y del tipo y nivel de modificación (Nugent, 2005; Sajilata et al., 2006).

El hecho de que el AR pase sin digerirse al intestino grueso, donde se vuelve disponible para su fermentación a las bacterias naturales residentes, hace que muestre una funcionalidad fisiológica similar a otras fuentes de fibra: de hecho, se asocia a una mejora la salud del colon, a un aumento el volumen fecal, y al control de la energía liberada (índice de glucemia). El método oficial de la AOAC 991.43 (Lee, Proxy y DeVries, 1992) para la declaración de fibra dietética del etiquetado de los alimentos, lo detecta como fibra dietética.

El almidón resistente no es un aditivo, es un componente natural de la dieta. Como se ve en la Tabla 2, ciertos cereales y legumbres son capaces de aportar cierta cantidad de AR, en proporción variable, pero su contribución depende, entre otros factores, de si han sufrido o no un proceso de elaboración (Brown et al., 1995). Además de las condiciones de procesamiento del alimento, la mayor susceptibilidad del almidón al ataque de enzimas se asocia a una pérdida de la integridad granular y la cristalinidad, y al incremento de la solubilidad parcial de los polisacáridos que lo constituyen. El contenido en almidón resistente está determinado por las características que presenta el almidón en el alimento, debido a esto es necesario contar con un control clínico real de los posibles beneficios fisiológicos que un alimento fortificado con almidón resistente aporta a la dieta de una persona sana.

Acciones fisiológicas del almidón resistente

Los almidones resistentes se digieren en el intestino grueso donde se degradan a ácidos grasos de cadena corta, CO_2, H_2 y CH_4. En este sentido se consideran un agente prebiótico.

Comparado con otras fibras dietéticas, el almidón resistente produce una mayor proporción de butirato, al que se asocia a una buena salud del colon y reducción de aparición de cáncer colorectal. El almidón resistente estimula selectivamente las bacterias probióticas productoras de butirato, que es un marcador de la salud colónica y es la mejor fuente de energía para las células de la mucosa del colon. Mientras que otros ácidos grasos cortos –como el propionato y el acetato– se incorporan al torrente sanguíneo, el butirato permanece localizado en el intestino grueso y ayuda a mantener una barrera de mucosa sana (Topping y Clinton, 2001). También se ha asociado a beneficios antitumorales –protección contra el cáncer de intestino grueso– y tendría amplias implicaciones en el funcionamiento y la salud del tracto intestinal como por ejemplo una mejora en la biodisponibilidad de minerales (Morais et al., 1996).

El AR de maíz de alto contenido en amilosa tiene un efecto sobre la respuesta glucémica o de glucosa en sangre. La respuesta glucémica mide el impacto de los alimentos ricos en hidratos de carbono sobre los niveles de glucosa en sangre. El índice glucémico es la metodología más conocida para cuantificar dicha respuesta. Los hidratos de carbono que se digieren lentamente provocan un máximo más bajo y más tardío en la curva de glucemia, y el área bajo la misma es menor (García-Alonso et al., 1998). Estas respuestas más atenuadas ayudan a mantener niveles de energía más equilibrados, especialmente en personas que necesitan estados de alerta continuados. Asimismo, un índice glucémico bajo se asocia a una mejora del control metabólico de la hiperlipidemia en individuos sanos (Jenkins et al., 1994, García-Alonso et al., 1998). Algunos estudios sugieren que los alimentos con baja respuesta glucémica afectan negativamente el apetito, haciéndolos útiles para su uso en el control de peso. Por el contrario, los picos altos en el índice de glucemia se han asociado a un mayor riesgo de diabetes, enfermedades del corazón y obesidad.

Funcionalidad del almidón resistente

El AR tiene un tamaño de partícula pequeño (<15 micras), lo que evita la textura y densidad propia asociada a los productos con alto contenido en fibra. Es de color blanco lo que permite su incorporación a una serie de alimentos sin alterar su color y de sabor suave. Tiene unas propiedades fisicoquímicas tales como formación de gel y capacidad de retención de agua, que hacen que sea útil en muchos alimentos. Sus propiedades físicas, en particular su baja capacidad de retención de agua, le permite ser un ingrediente funcional que aporta al producto final una buena manipulación en su procesamiento, crujibilidad y mejora la textura final del producto. Estas propiedades hacen que sea posible sustituir la harina por almidón resistente (Sajilata et al., 2006).

Por lo tanto, el uso del AR es interesante por dos razones: (a) el enriquecimiento de fibra y los potenciales beneficios fisiologico del AR, los cuales son similares a los de la fibra; (b) sus propiedades funcionales únicas, dando productos de alta calidad que no se alcanzaría con otras fibras insolubles tradicionales.

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OBJETIVOS

OBJETIVOS

El objetivo principal del presente trabajo es evaluar los efectos de la inclusión de almidón resistente en una formulación de un producto de bollería tradicional (magdalena) como fuente de fibra funcional.

Objetivos específicos

Seleccionar una formulación "control" y poner a punto el método de fabricación del producto de bollería.

Estudiar las propiedades reológicas y de consistencia de la masa cruda (25ºC), y el efecto de la temperatura sobre la masa (85ºC).

Estudiar las características texturales más relevantes del producto final. Se buscarán otras características del mismo que influyan en su aceptabilidad: forma, altura, volumen, y recuento y distribución de celdas de aire.

Estudiar el efecto del almidón resistente (AR) a distintas concentraciones sobre las propiedades y caracteristicas anteriores y además evaluar las características sensoriales que aporta la inclusión de AR en el producto de bollería. Estudiar la aceptabilidad del nuevo producto con un panel de consumidores.

CAPÍTULO 1

INFLUENCE OF THE DOSING PROCESS ON THE RHEOLOGICAL AND MICROSTRUCTURAL PROPERTIES OF A BAKERY PRODUCT

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Abstract

This study examined the effect of the use of an automatic dosing unit on the rheological, microstructural, and textural properties of an aerated batter for preparing a bakery product. Two cases were studied: in one the batter was dosed manually into the paper cups and in the other the batter was dosed automatically into the paper cups. The flow properties of the batter dosed by the two methods showed significant differences in the consistency index, although in the flow index there was no difference. The mechanical spectra of batters at 25 ºC and at 85 ºC and the evolution of G' and G'' with rising temperature (from 25 ºC to 85 ºC) were determined by dynamic rheological tests. Passing the batter through the automatic dosing unit produced an increase in both moduli (G' and G'') at 25 ºC and there was no difference in the values of G' and G'' at 85 ºC. The microstructure of the two batters was analyzed by cryo-scanning electron microscopy (cryo-SEM). Observation of the batters' microstructure revealed many changes that could be related to the dosing step. Texture Profile Analysis (TPA) at 50 % was used to evaluate the effects of the use of the automatic dosing unit on the textural properties of the final baked products prepared with batter that had been dosed by the unit or manually and very similar results were obtained in both cases.

Key words: Batters; Muffins; Rheology; Texture; Microstructure; Cryo-scanning electron microscopy (Cryo-SEM)

1. INTRODUCTION

Many bakery products (American muffins, sponge cakes, angel cake, etc) are made by mixing flour, sugar, milk, eggs and a leavening agent. Good control of the preparation process ensures good final product properties. The rheological properties of batters depend on many factors besides the ingredients and their proportions; the mixing and beating processes can affect these properties which, in turn, determine the batter behavior and the textural properties of the final baked product. Textural properties are important quality parameters for this type of product. Physical and structural changes during aerated batter processing may alter their performance during baking or the quality of the final product. The rheological properties of fluid foods are complex and depend on many factors such as composition, shear rate, duration of shearing, and previous thermal and shear histories. The ingredients of the batter and the processing conditions during baking have been related to the rheology and texture of the final product. Fat content was an important parameter studied. Khouryied, Aramouni and Herald (2005) investigated the effect of incorporating xanthan gum, maltodextrin and sucralose to made a no-sugar-added/low fat muffin, and found that removing the fat from the muffin was responsible for the increase in hardness and chewiness. Similar results were observed by Grigelmo-Miguel, Carreras-Boladeras and Martín-Belloso (2001) who observed an increase in hardness and chewiness of muffins when oil was substituted for dietary fiber in reduced-fat muffin. Shearer and Davies (2005) investigated changes in muffins when flaxseed oil to low fat content and flaxseed meal as a source of fiber were incorporated, they found an increase in batter viscosity with the increase of the content of flaxseed meal the firmness and the elasticity decreased with the content of flaxseed meal. In the case of non-aerated batters, Sai Manohar and Haridas Rao (1999) investigated the effects of different mixing methods on the rheological characteristics of biscuit dough and on the quality of biscuits. They showed that the creaming method produced good quality biscuits with good crispness. Navickis (1989) investigated the changes in some rheological properties of corn flour doughs fortified with wheat gluten for a series of different mixing times, he observed that the storage modulus (G') increased and the shear loss modulus (G'') decreased with increasing mixing times. As regards aerated batter, Bosman, Vorster, Setser and Steyn (2000) evaluated the effect of batter refrigeration on the quality characteristics of muffins with different percentages of oil replacement and reported that the experimental muffins baked from refrigerated batter, although different from freshly prepared muffins, were still of comparable quality for all the characteristics measured. Baik, Marcotte and Castaigne (2000) tested the quality parameters of four different types of cake in two different ovens and found that the position of cakes in the oven was not critical for the textural quality of the final product.

There is no literature on the effect that dosing processes may have on the properties of batters and final baked products. The objective of this study was to determine whether the use of an automatic dosing unit has any effect on the rheological and microstructural properties of an aerated batter for muffins and in the textural characteristics of the final baked product.

2. MATERIALS AND METHODS

2.1 Batter and muffin preparation

The batter formulation consisted of wheat flour (Harinera Vilafranquina, S.A., Teruel, Spain) (composition according to the miller: 14.5 % moisture, 10.1 % protein); sugar (Azucarera Ebro, Madrid, Spain); liquid pasteurized egg white and liquid pasteurized yolk (Ovocity, Llombay, Spain); full-fat milk; refined sunflower oil, sodium bicarbonate, citric acid and grated lemon peel. The percentage of the different ingredients in the batter formulation is given in Table 1.

Table 1. Composition of the batter formula.

Wheat flour (%)	26
Sugar (%)	26
Egg white (%)	14
Yolk (%)	7
Milk (%)	13
Oil (%)	12
Sodium bicarbonate (%)	1.03
Citric acid (%)	0.79
Grated lemon peel (%)	0.18

All composition percentages are given on a weight basis

The egg white was whipped in a mixer (Kenwood Major Classic, UK) for 2 min at maximum speed. Sugar was then added and mixed in for 30 s at speed 7. Egg yolk, citric acid and milk (6.5 %) were added and mixed in at speed 3 for 1 min. Wheat flour, sodium bicarbonate and grated lemon peel were added and mixed in at speed 3 for 1 min. Oil and milk were added and mixed in at speed 4 for 3 min. Two procedures were followed: one was to place the batter manually into the paper muffin cups (5 cm in diameter), weighing in 40.5 g of batter each time; the other was to pass the batter through an automatic dosing unit (positive displacement pumps, output shaft speed=109 r.p.m., output shaft torque=7.6 N.m.) (Edhard Corp., Hackettstown, USA), filling each paper muffin cup with 40.5 g of batter. The muffins were baked in a conventional oven for 6 min at 225 ºC and for a further 6 min at 175 ºC. The oven was always the same, the trays were always the same, they were placed in the same place in the oven, and the number of muffins baked was always the same.

2.2 Rheological properties

Special attention was taken to maintain the same previous thermo-mechanical history in the samples before the rheological tests.

Accordingly, after batter manufacturing and before the rheological test, the batters were always kept for 1 h at 25 ºC. Samples were allowed to rest in the measurement position for 2000 s, as equilibration time. To protect against dehydration during long measurement times, vaseline oil (Panreac Química S.A.) was applied to the exposed surfaces of the samples and a covering glass cup was employed.

2.2.1 Flow properties

The flow properties of the batters were studied using a Physica Rheolab MC

120 rheometer (Paar Physica, Stuttgart, Germany) equipped with a thermostatic bath (Physica Viscotherm VT10). A 50 mm diameter plate-plate sensor geometry with a 1-mm gap between the plates was employed, which was considered large enough with regard to the starch granule size (maximum size around 35 µm). A continuous ramp was applied and apparent viscosity was measured as a function of shear rate over the range 0.5-100 s^{-1} taking 30 points linearly in time at 25 ºC. Raw shear rates were corrected by a derivation resembling that used for the Weissenberg-Rabinowitsch equation for capillary flow (Macosko, 1994). Two replicates of each flow curve were run with good reproducibility since the differences between duplicates were less than 10 %.

2.2.2. Viscoelastic properties

Linear viscoelastic properties were studied with a RheoStress 1 controlled stress rheometer (Haake, Karlsruhe, Germany) equipped with a Phoenix II P1-C25P refrigeration circulation bath (Haake, Karlsruhe, Germany) and plate-plate sensor geometry (60 mm in diameter) with a 1-mm gap.

Stress sweep tests (1 Hz at 25 and at 85 ºC) were made to determine the linear viscoelastic region (LVR) of all samples. Temperature dependence was studied by applying a temperature sweep at 1 Hz from 25 ºC to 85 ºC at a heating rate of 0.017 ºC/s. During the temperature sweep the applied stress was always self adjusted in order to keep measurements in all range of temperatures studied within the linear viscoelasticity regime, i.e. taking into account the critical strain for the onset of non-linear response. Additionally, frequency dependence tests were conducted from 10 to 0.01 Hz at the beginning and end of the temperature sweep: 25 ºC and 85 ºC, respectively. Three replicates of each oscillatory dynamic test were conducted for each kind of batter. The storage and loss moduli values used to determine the average data were accurate (differences below ± 10 %).

2.3. Batter microstructure

Cryo-Scanning Electron Microscopy (Cryo-SEM) was used to perform structural analysis of the batters at 25 ºC. A cryostage CT 1500 C (Oxford Instruments) linked to a JEOL JSM 5410 electron microscope was used. The samples were placed on the cryo-specimen holder and cryo-fixed in slush nitrogen (T<-210 ºC), then quickly transferred to the cryo-unit in the frozen state, where each sample was fractured using a movable blade, sublimated for 45 minutes at -90 ºC (the final point was determined by direct observation at 5 kV) and gold-coated for imaging purposes. Samples were viewed using 10 kV accelerating voltage at a 15 mm distance and T<-130 ºC.

2.4. Textural properties of the final baked product

Textural characteristics of the baked muffins were determined by using a texture profile analysis (TPA) applied with a TA-XT.plus Texture Analyzer (Stable Micro Systems, Godalming, UK). A 2.5-cm sided cube of the muffin crumb was evaluated after removing the upper and the lower parts. The texture parameters were determined with a test speed of 1.0 mm/s, and strain of 50 % of the original cube height, a 5-s time was elapsed between compression cycles. The compression was performed using a 75 mm aluminium plate (P/75); the muffins were prepared twice on different days and six cubes from each muffin formulation were measured. The cubes were compressed twice to give a TPA from which the three prymary textural parameters (Pons and Fiszman, 1996) were obtained: hardness, springiness, and cohesiveness, as calculated by the texturometer software. Other studies have used the same method to analyze muffins textural parameters: Grigelmo-Miguel, Carreras-Boladeras, and Martín-Belloso (1999), Singh Gujral et al. (2003) and Khouryieh et al. (2005).

2.5. Statistical analysis

Analysis of variance was applied to the texture and rheology data. In order to study the differences among the samples, least significant differences were calculated by Fisher's test. These analyses were performed using the Statgraphics Plus 2.1 package (Bitstream, Cambridge, Massachussets).

3. RESULTS AND DISCUSSION

3.1. Flow properties

Apparent viscosity values versus shear rate at 25 ºC for the manually dosed batter and the batter that had passed throught the dosing unit are presented in Figure 1.

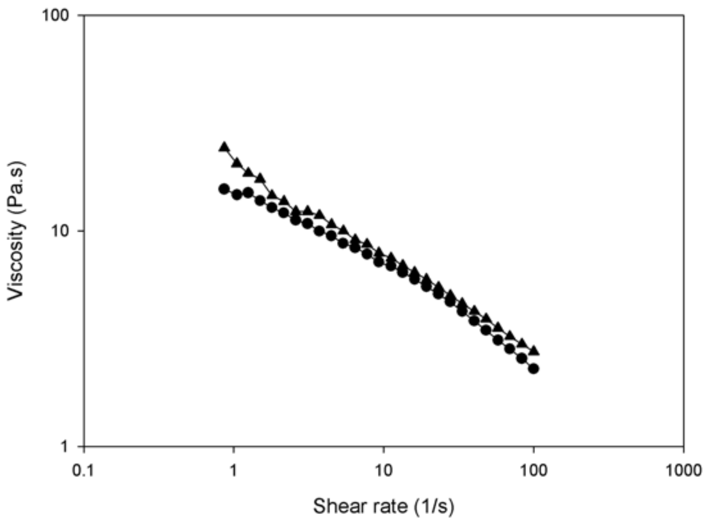

Figure 1. Flow curves of manually dosed batter (circles) and of the batter that has passed through the automatic dosing unit (triangles) at 25ºC.

In both cases shear-thinning behavior was found in the shear rate range studied (0.490-100 s^{-1}), fitting the power-law equation fairly well (r > 0.99)

$$\eta = k \cdot \dot{\gamma}^{n-1}$$

where *k* is the consistency index, *gamma dot* is the shear rate and *n* is the flow index. The calculated values for *k* and *n* are presented in Table 2. Passing through the automatic dosing unit increased the consistency index of the batter significantly, although it did not affect the flow index.

Table 2. Consistency index values and flow behavior index values for the manually dosed batter and for the batter that has passed through the automatic dosing unit.

Automatic Doser	K (Pas^n)	n
No	17.3a (0.4)	0.6a (0.01)
Yes	21.9b (0.8)	0.6a (0.01)

Values in parentheses are standard deviations. Means in the same column without a common letter differ ($p < 0.05$) according to the least significant difference multiple range test.

3.2. Viscoelastic properties

3.2.1. Gelation

To evaluate the effect of heating on the batters' viscoelastic properties, the evolution of the elastic modulus (G') and the viscous modulus (G'') from 25 to 85 ºC (maximum temperature achieved by the water heating system) was studied by applying a temperature sweep at a speed of 0.017 ºC/s. The values obtained for the batter dosed manually and for the batter that had passed through the dosing unit are shown in Figure 2.

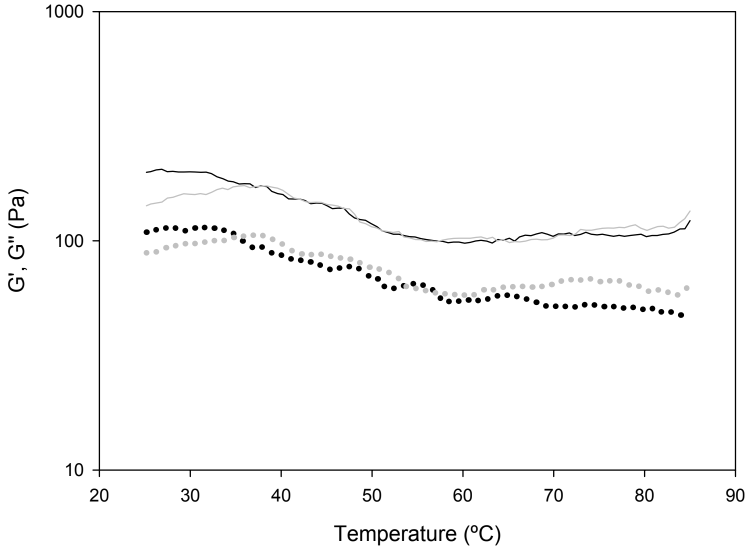

Figure 2. Evolution with temperature of G' (solid line) and G'' (dotted line) values of the manually dosed batter (black) and the batter that has passed through the automatic dosing unit (grey). Heating rate: 0.017 ºC/s. Strain wave amplitude: 0.0007. Frequency: 1 Hz.

In both samples, the initial increase in temperature provoked a decrease in both viscoelastic moduli up to a temperature of circa 55 ºC. These results were in agreement with previous results, as Dogan (2002) reported that the initial tendency of the moduli values of doughs heated to gelatinisation temperatures to diminish progressively up to a certain temperature indicated decreased interactions in the system, Sanz*,* Fernández, Salvador, Muñoz and Fiszman (2005) studied a temperature range from 10 to 60 ºC and stated that the batter (a batter formula for frying) showed a decrease in the │G*│modulus with the initial increase in temperature. From the stabilization temperature (≈55 ºC) until the maximum temperature of the experiment (85 ºC) no increase in the viscoelastic functions was found. The increase in the viscoelastic functions with temperature is associated to the starch gelatinization process (Dogan, 2002 and Salvador, Sanz and Fiszman ,2005). The fact that this increase was not found in the muffin batter implies a delay in the starch gelatinization process, probably due to a decrease in the available water in the system.

This pattern of behavior was the same for the manually dosed batter and for the batter that had passed through the dosing unit. However, the processed batter showed higher values of both G’ and G’’ at the beginning of the temperature ramp (25 ºC).

3.2.2. Mechanical spectra

To obtain more information about the possible differences in the viscoelastic behavior of the batters, the frequency dependence of the moduli at the initial (25 ºC) and final (85 ºC) temperatures of the heating sweep were studied.

The evolution with frequency of the G’ and G’’ of both batters at 25 ºC and 85 ºC is shown in Figures 3 and 4, respectively.

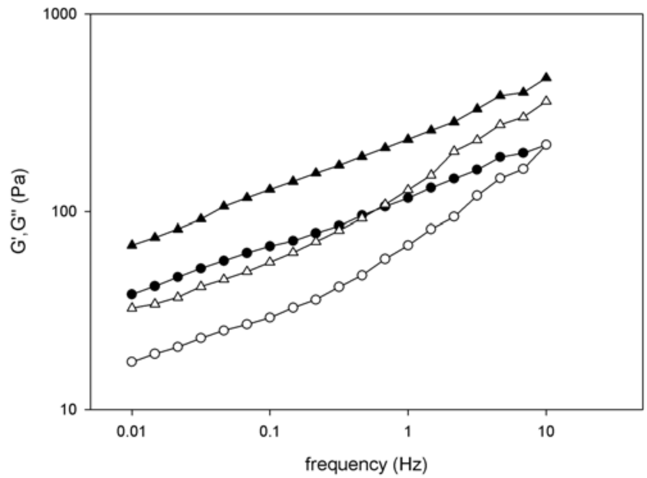

Figure 3. Mechanical spectra of manually dosed batter (circles) and batter that has passed through the automatic dosing unit (triangles) at 25 ºC. G' values (solid symbols) and G'' (open symbols).

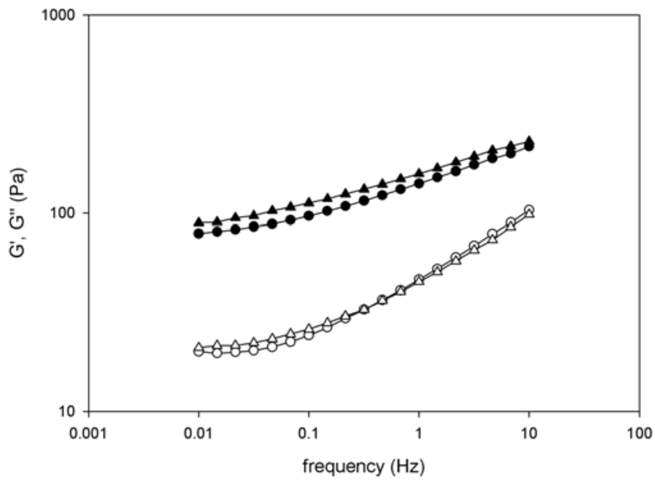

Figure 4. Mechanical spectra of manually dosed batter (circles) and batter that has passed through the automatic dosing unit (triangles) at 85 ºC. G' values (solid symbols) and G'' (open symbols). Shear stress wave amplitude: 0.6 Pa

In additon, the stress sweeps previously performed to determine the linear viscoelastic range are shown in Figures 5 and 6.

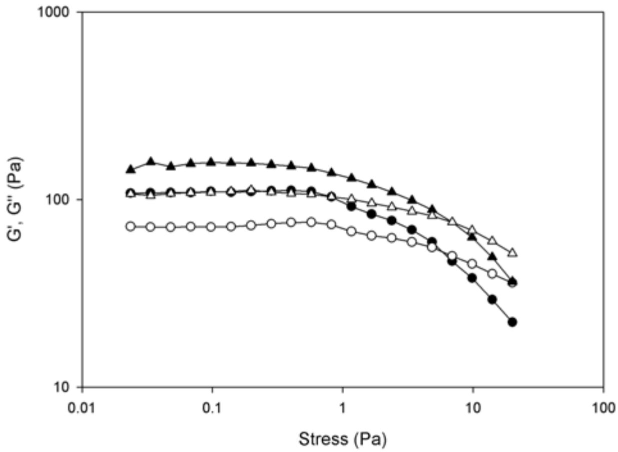

Figure 5. Shear stress wave amplitude: 0.1 Pa Stress sweeps at 25 ºC for manually dosed batter (circles) and batter that has passed through the automatic dosing unit (triangles). G' values (solid symbols) and G'' (open symbols). Frequency: 1 Hz.

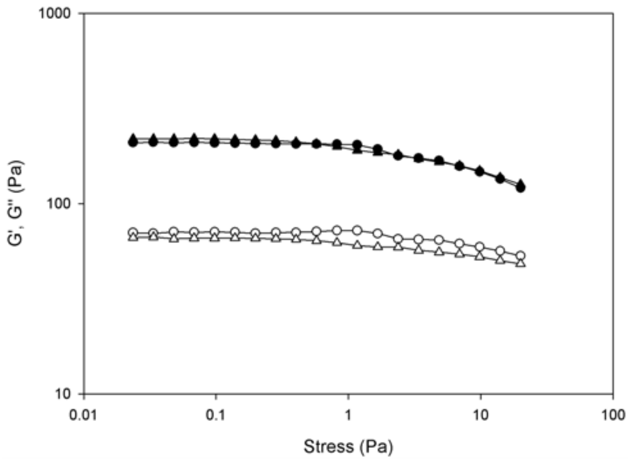

Figure 6. Stress sweeps at 85 ºC for manually dosed batter (circles) and batter that has passed through the automatic dosing unit (triangles). G' values (solid symbols) and G'' (open symbols). Frequency: 1 Hz.

In both batters the mechanical spectra at 25 ºC (Figure 3) showed the typical behavior of a soft gel, with values for G' slightly higher than those for G'' and significant frequency dependence of both moduli within the frequency range studied. Similarly to the results found in the temperature sweep, passage through the automatic dosing unit produced an increase in both moduli. However, no significant differences were found in the tg delta (G''/G') values, denoting that this step produced no changes in the contribution of the two moduli to the viscoelastic behavior of the samples.

With regard to the mechanical spectra of the batters at 85 ºC (Figure 4), the dynamic viscoelastic behaviour may be ascribed to the formation of an stronger gel than that found at 25 ºC, although it was still soft. The difference between the two moduli values increased and a well-developed plateau region with a minimum in G'' and a slight frequency dependence of G' were observed. At this temperature, no differences were found between the two batters, denoting that the differences found at 25 ºC did not contribute to future differences in the heated samples.

3.3. Batter microstructure

The microstructure characteristics of wheat flour doughs are highly dependent on preparation procedures (Rojas, Rosell, Benedito de Barber, Pérez-Munuera and Lluch, 2000). On mixing flour and water, the resulting batter presents a reticular structure of proteins and soluble solutes in the form of a matrix with embedded starch granules. The starch granules are dispersed in the continuous matrix. These granules are divided into two different populations of wheat starch granules: the larger ones are lentil shaped and the smaller ones are round (Llorca, Hernando, Pérez-Munuera, Fiszman and Lluch, 2001). The electron micrographs obtained are shown in Figures 7 and 8.

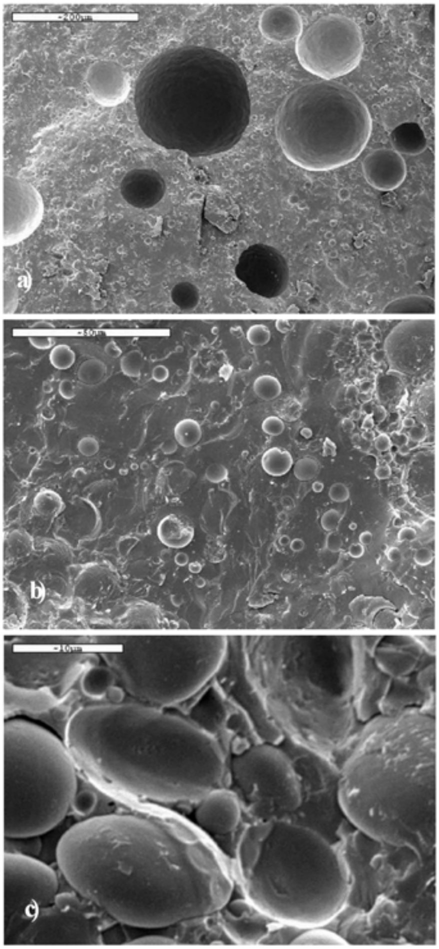

Figure 7. Cryo-SEM microphotograph. Batter dosed manually. ***(a) (200X), (b) (1000X), (c) (3500X)***

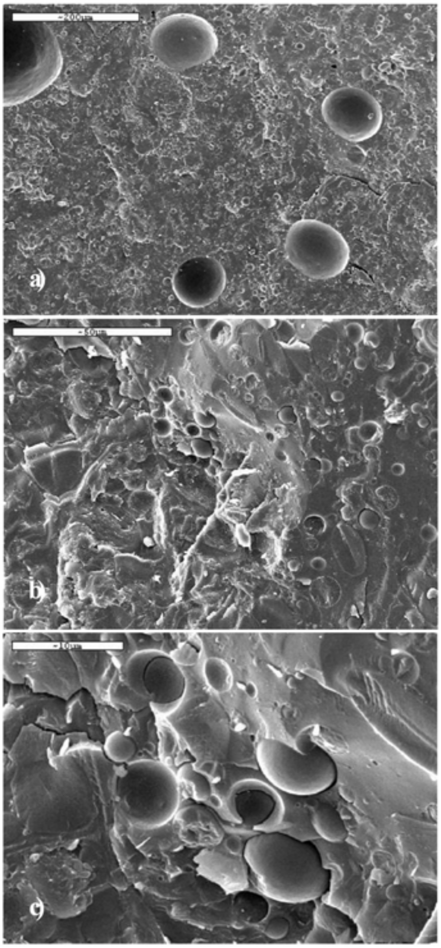

Figure 8. Cryo-SEM microphotograph. Batter that has passed through the automatic dosing unit. ***(a) (200X), (b) (1000X), (c) (3500X)***

The batter that had passed through the automatic dosing unit showed greater compactness of the microstructural elements (Figure 8a) and a decrease in the fat globules size in comparison to the batter that had not passed through the automatic dosing unit (Figure 7a).

At higher magnification (Figures 7b and 8b) the main protein matrix with embedded groups of cellular components, mainly starch granules from the wheat flour can be visualized. The greater compactness of the batter that had passed through the automatic dosing unit can be also observed.

The two distinct populations of starch granule sizes may be observed in Figure 7c and Figure 8c. In Figure 8c some starch granules appeared deformed as a consequence of the dosing unit step.

These results indicate that the dosing unit step affected the batter microstructure.

3.4. Textural properties of the final baked product

The effects of the dosing unit step on the textural parameters of the final baked product were investigated. The results of the parameters measured (hardness, springiness and cohesiveness) are shown in Table 3.

No significant differences between the muffins made with the batter dosed manually and with the batter that had passed through the automatic dosing unit were found for any of the textural parameters.

Table 3. TPA parameters for muffins made with the manually dosed batter and with the batter that has passed through the automatic dosing unit.

Automatic Doser	Hardness (g)	Springiness	Cohesiveness
No	330 a (51)	0.70 a (0.06)	0.70 a (0.02)
Yes	321 a (47)	0.80 a (0.06)	0.70 a (0.01)

Value without parentheses are standard deviations. Means in the same column without a common letter differ ($p < 0.05$) according to the least significant difference multiple range test.

4. CONCLUSIONS

The results showed that the use of a dosing unit as an additional step in batter processing modified the batter at a microstructural and structural level. The use of a dosing unit as an additional step in batter processing produced an increase in the compactness and a reduce in the fat globule size in the resulting batters. These microstructural changes were associated to an increase in viscosity and in both G' and G'' at 25 ºC. At 85 ºC the rheological behavior did not show any difference among the two batters, reflecting that the structural changes occurring to the batter during heating are not affected by the dosing step. This aspect is also reflected by the absence of differences in the mechanical properties of the muffins measured by TPA.

However, the results of this work show that the changes induced by an automatic dosing step, or by other industrial practices, could affect the batters' structure. This work is a first step towards developing a methodology to study the changes that could occur in the batter during different steps of the process. Even though the changes are minor in this study, they would be much more distinctive when using more energetic processes.

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CAPÍTULO 2

MUFFINS WITH RESISTANT STARCH: BAKING PERFORMANCE IN RELATION TO THE RHEOLOGICAL PROPERTIES OF THE BATTER

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Abstract

The effect on baked muffins of progressively replacing wheat flour with resistant starch (RS) was studied. Muffin volume and height and the number and area of gas cells decreased significantly when the RS level reached about 15% (by weight of total formulation) or higher. Rheological properties of the raw batters were studied: the mechanical spectra of batters at 25ºC, the evolution of the dynamic moduli (G' and G'') with rising temperatures (from 25ºC to 85ºC) and the mechanical spectra at 85ºC were obtained from oscillatory rheological tests. The decrease in the viscosity and in the elastic properties of the muffin batter as the flour was increasingly replaced by RS was related to the baking performance of the final baked products.

Key words: Resistant starch; Batters; Muffins; Rheology; Gas cell.

Abbreviations: RS, resistant starch; SAOS, small amplitude oscillatory shear; SG, specific gravity

1. INTRODUCTION

Resistant starch (RS) has been defined as the sum of starch and starch degradation products not absorbed in the small intestine of healthy individuals (Asp and Björck, 1992). According to the latest definition of dietary fibre (De Vries, 2003), RS is considered dietary fibre and is determined as such by the official method for the regulatory determination of Total Dietary Fibre, AOAC 991.43 (Haralumpu, 2000). Some of the benefits of RS resemble those of traditional fibre and others are unique to RS. One of the interesting characteristics of RS is its pattern of fermentation in the colon, principally the profile of short chain fatty acids.

The intake of fibre and fibre-containing foods is below the recommended levels in all Western countries. For this reason, efforts have been made to develop fibre-enriched foods. Ideally, the foods to fortify are those that taste good and are often eaten. Several dietary fibres have been employed to produce high fibre content muffins and cakes. Shafer and Zabik (1978) compared the effect of replacing 30% of the flour with different dietary fibre sources (wheat, corn, soy, and oat brans) on raw batter and final cake quality parameters measured both instrumentally and sensorially. Cakes with wheat bran had a little effect on cake quality, cakes made from corn bran had the largest volume of any cake, and cakes with soy and oat bran were scored with a poor flavor. The suitability of apple fibre (4%) in comparison to wheat and oat brans was studied by Chen et al. (1988). The addition of this fibre produce an increase in muffin density, low density is associated with good muffin quality. Isolated fibres from wheat, pineapple and field bean seed hulls were included (5% w/w) in a sponge cake preparation without altering the volume and sensory properties of the final product (Sreenath et al., 1996). Grigelmo-Miguel et al. (2001) studied the feasibility of peach dietary fibre to replace oil in a standard muffin recipe; acceptability studies revealed no differences between the control and muffins with 4% of peach fibre. In comparison to traditional fibre, RS possesses the advantage of its white colour and low water retention properties (Yue and Waring, 1998), so it should cause less alteration to the sensory properties of the final baked product as well as to its manufacturing process (Wepner et al., 1999). When RS was used to replace 12.5% of the shortening, yellow layer cake quality was improved (Lin et al., 1994). No many information about incorporating RS into muffins or cake systems appears to have been published.

A muffin batter is a complex mixture of interacting ingredients; basically, a standard muffin formula is composed of a high level of sugar and variable levels of fat, flour, eggs, and baking powder. Other commonly used ingredients are emulsifiers, preservatives, and milk powder. Muffins are characterized by a typical porous structure and high volume. To obtain such a structure, a stable batter lodging many tiny air bubbles is required. The bubbles are produced during the mixing process. After mixing, the bubbles will act as nuclei and grow in size when the carbon dioxide gas generated by the baking powder leavens the product during baking. Eggs, egg white and, to a lesser extent, milk proteins are important foam stabilizers, slowing down the coalescence of air bubbles. Shortening and oil are used to give a softer structure and avoid a dry mouth feel (Lallemand Baking update, 2000). Gelatinization of the starch from the flour and protein denaturising sets the structure during baking. Sucrose increases the starch gelatinisation and protein denaturising temperatures, giving the cake time to rise (Hoseney, 1994).

The viscous behaviour of the batter system is a controlling factor in the final cake volume, due to its effects on bubble incorporation and movement (Handleman et al., 1961; Bath et al., 1992; Kim et al., 2001). The rate at which bubbles rise due to buoyancy is inversely proportional to viscosity. Thus, rapidly rising bubbles in a low-viscosity cake batter may result in cake volume loss. Higher cake batter viscosities help to incorporate more air bubbles into the batter and keep them from escaping from the mass, giving the cake system more stability. Coalescence is the most important process by which cells disappear in porous bakery products.

Studying viscoelastic behaviour through small amplitude oscillatory shear (SAOS) gives very valuable information about the structural properties of a system. Information about the oscillatory rheological characteristics would help to understand the structure of the raw batter and its changes during heating.

The aims of this investigation were to study the effect of replacing wheat flour with different amounts of RS on the baking performance of a muffin batter formulation and to relate this effect to the linear viscoelastic properties of the raw batter before, during and after heating to a certain temperature.

2. EXPERIMENTAL

2.1. Batter and muffin preparation

Five formulations were prepared using the same quantity of all the ingredients except the flour and RS, which were 26/0, 21/5, 16/10, 11/15 and 6/20 per cent respectively. The ingredients used in the preparation of the muffin batters were wheat flour (Harinera Vilafranquina, S.A., Teruel, Spain) (composition data provided by the supplier: 14.5% moisture, 10.1% protein); RS (HI-maize 1043, National Starch Food Innovation, Manchester, United Kingdom) (composition data provided by the supplier: 12% moisture, 63.9% dietary fibre); 26% sugar (Azucarera Ebro, Madrid, Spain); 14% liquid pasteurized egg white and 7% liquid pasteurized yolk (Ovocity, Llombay, Spain); 13% full-fat milk (Puleva Food, Granada, Spain); 12% refined sunflower oil (local supermarket); 1.03% bicarbonate of soda (A. Martínez, Cheste, Spain); 0.79% citric acid (A. Martínez, Cheste, Spain), and 0.18% grated natural lemon peel. The egg white was whipped in a mixer (Kenwood Major Classic, UK) for 2 min at speed 7 (maximum). Sugar was then added and mixed in for 30 s at speed 7. Egg yolk, citric acid and milk (6.5 %) were added and mixed in at speed 3 for 1 min. Wheat flour, RS, bicarbonate of soda. and grated lemon peel were added and mixed in at speed 3 for 1 min. Oil and milk were added and mixed in at speed 4 for 3 min. The batter was placed in an automatic dosing unit (positive displacement pumps, output shaft speed=109 rpm, output shaft torque=7.6 N.m) (Edhard Corp., Hackettstown, USA) and each paper muffin cup (50-mm diameter) was filled with 40.5 g of batter. The muffins were baked in a conventional oven for 6 min at 225ºC and a further 6 min at 175ºC. The oven and oven trays were always the same, the trays were placed at the same level in the oven and the number of muffins baked was always the same. The muffins from each formulation were prepared twice, on different days, with twenty-four muffins in each batch.

2.2. Specific gravity of the batter

The specific gravity (SG) of the raw batter was measured with a small cup of known volume. It was determined gravimetrically by dividing the weight of this known volume of batter by the weight of an equal volume of water. The measurements were made in triplicate.

2.3. Rheological properties of the batter

During the rheological determinations, special attention was paid to maintaining samples with the same thermo-mechanical history before testing. Accordingly, the batters were all kept at 25ºC for 1 h after batter preparation before the rheological test. The samples were then allowed to rest in the measurement cell for a 1400 s equilibration time. To protect against dehydration during long measurement times, vaseline oil (Panreac Química S.A.) was applied to the exposed surfaces of the samples and they were covered with a glass cup.

2.3.1 Flow properties

The flow properties of the muffin batters were studied using a Physica Rheolab MC 120 rheometer (Paar Physica, Stuttgart, Germany) equipped with a thermostatic bath (Physica Viscotherm VT10). A 50-mm diameter plate-plate sensor geometry with a 1-mm gap between the plates was employed, which was considered large enough with regard to the starch granule size (maximum size around 35 μm). A continuous ramp was applied and apparent viscosity was measured as a function of shear rate over the 0.5-100 s^{-1} range, taking 30 points linearly in time at 25ºC. Two replicates of each flow curve were run with good reproducibility since the differences between duplicates were less than 10%. All curves were adjusted to the Ostwald model following the power-law equation:

$$\eta = k \cdot \dot{\gamma}^{n-1}$$

Where η is the apparent viscosity, k is the consistency index, *gamma dot* is the shear rate and n is the flow index

Evolution of viscosity with temperature was study applying a shear rate of 1 s^{-1} from 25 to 90ºC at a heating time of 0.017ºC/s using concentric cylinders Z2 DIN (100 cm^3). Two replicates were conducted for control and 20% RS batters.

2.3.2. Viscoelastic properties

Linear viscoelastic properties were studied with a RheoStress 1 controlled stress rheometer (Haake, Karlsruhe, Germany) equipped with a Phoenix II P1-C25P refrigeration circulation bath (Haake, Karlsruhe, Germany) and serrated plate-plate sensor geometry (60 mm in diameter) with a 1-mm gap. Stress sweep tests (1 Hz at 25 and at 85ºC) were made to determine the linear viscoelastic region of all samples. Temperature dependence was studied by applying a temperature sweep at 1 Hz from 25ºC to 85ºC at a heating rate of 0.017ºC/s. During the temperature sweep the applied stress was always self-adjusted in order to keep measurements throughout the range of temperatures studied within the linear viscoelasticity regime, i.e. taking into account the critical strain for the onset of non-linear response. Additionally, frequency dependence tests were conducted from 10 to 0.01 Hz at the beginning and end of the temperature sweep, at 25ºC and 85ºC respectively. Three replicates of each oscillatory dynamic test were conducted for each kind of batter. The storage and loss moduli values used to determine the average data were accurate (differences below ± 10 %).

2.4. Physical characteristics of the baked muffins

Muffin height was measured from the highest point of the muffin to the paper muffin cup bottom after 1h cooling at room temperature.

The muffins were cut transversally (30mm from their bottom part) and images of the freshly cut surface of the crumb were captured using a Hewlett Packard flatbed scanner (HP 4300c, Hewlett Packard, USA. Images were analyzed using the UTHSCSA *ImageTool* program developed at the University of Texas Health Science Centre at San Antonio, Texas, (available from the Internet by anonymous FTP from maxrad6.uthscsa.edu). The number and area of gas cells were obtained by using the following equations:

$$\text{area} = \pi \times a \times b$$

where a is the semi major axis of the gas cell and b is the semi minor axis of the gas cell.

The gas cell calculations were made on 5 muffins per formulation. Gas cells with semi axis below 0.5 mm were not counted.

2.5. Statistical analysis

Analysis of variance (ANOVA) was applied to study the differences among the samples; least significant differences were calculated by Fisher's test and the significance was determined at $p< 0.05$. These analyses were performed using SPSS for Windows Version 12 (SPSS Inc., USA).

3. RESULTS AND DISCUSSION

3.1. Physical characteristics of the baked muffins

Images of the transversally cut surface of the baked muffins are shown in Figure 1.

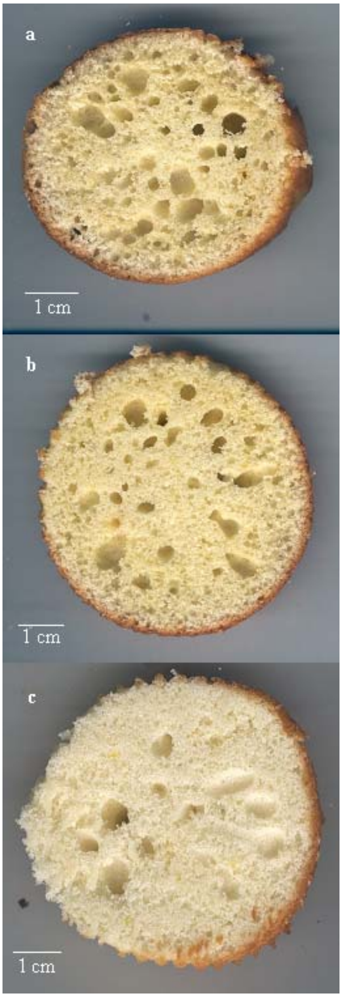

Figure 1. Digital images of muffins with different levels of RS. ***(a) control, (b) 10%, (c) 20%.***

The increase in RS concentration significantly decreases the number and area of gas cells and the height of the final baked muffins (Table 1).

Table 1. Mean values of some characteristics of baked muffins prepared with increasing levels of resistant starch.

Resistant starch (% by weight)	**Muffin height (cm)**	**Number of gas cells**	**Gas cell area (mm^2)**
0 (control)	4.70 a (0.19)	25 a (3)	2.6 a (0.2)
5	4.59 ab (0.17)	19 ab (3)	1.3 bc (0.2)
10	4.50 b (0.15)	17 b (5)	1.5 b (0.3)
15	4.12 c (0.35)	15 b (3)	1.3 bc (0.2)
20	3.84 d (0.38)	7c (1)	0.9 c (0.2)

Values in parentheses are standard deviations. Means in the same column without a common letter differ ($p < 0.05$) according to the least significant difference multiple range test.

These results are in agreement with Lin et al. (1994). These authors found that as the amount of shortening replaced by RS increased, the crumb matrix became more compact and a general decrease in cake volume and softness occurred. Similar results were found by Baixauli et al. (2007) where the addition of RS produced a decrease in resilience and springiness because the product matrix became denser and therefore, the samples were less able to recover after deformation. A porous structure is associated with a softer, lighter crumb and thus with a higher sensory quality (Morr et al., 2003). A volume reduction in bread with β-glucan addition was reported attributable to gluten dilution, resulting in an underdeveloped gluten network; this would limit the extend of dough inflation and gas cell stability during proving, with a reduced loaf volume (Symons and Brennan, 2004)

3.2. Flow properties and specific gravity of the raw batter

Apparent viscosity values versus shear rate for the muffin batters prepared with different RS concentrations are shown in Figure 2. The increase in RS content produced a progressive decrease in the apparent viscosity values.

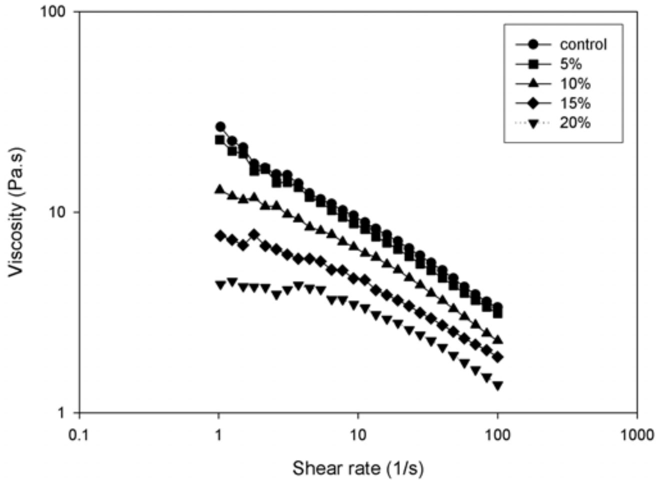

Figure 2. Influence of RS level on the flow properties of a muffin batter at 25ºC.

The shear thinning behaviour was observed; within the experimental shear rate range studied (from 1 to 100 s^{-1}) it fitted the power-law equation (r>0.99) fairly well. As the flow index, *n*, tends towards 1, shear thinning properties become less pronounced (newtonian behaviour would be achieved if n=1). The increase in RS content produced a significant decrease in consistency values, K, and in shear thinning behaviour (n value closer to 1), indicating the existence of a less complex structure, more similar to water (Table 2).

Table 2. Consistency index (K), flow behaviour index (n) and specific gravity (SG) at 25ºC for muffin batters with increasing levels of RS.

RS (% by weight)	**K** **(Pas^n)**	**n**	**SG**
0 (control)	23.6 a (2.9)	0.55 a (0.01)	1.044 a (0.018)
5	16.4 b (1.8)	0.58 ab (0.03)	1.047 a (0.006)
10	15.6 b (0.8)	0.60 b (0.02)	1.017 ab (0.015)
15	7.7 c (0.9)	0.71 c (0.02)	1.005 b (0.01)
20	3.7 d (0.3)	0.85 d (0.03)	0.987 b (0.035)

Values in parentheses are standard deviations. Means in the same column without a common letter differ (p<0.05) according to the least significant difference multiple range test.

As the increase in the RS content of the muffin batter was associated with a decrease in wheat flour content, the observed effect may be attributed to the dilution of the wheat flour protein in the system, which is an important component for structure development during mixing (Loewe, 1993).

In fact, the decrease in the viscosity of the raw batter as RS levels increased is not a favourable factor for batter stability and the quality of the final baked product.

Many authors have related a decrease in raw batter viscosity with low final quality, mainly associated with an increase in the buoyancy of the air bubbles and a denser final texture (Lakshminarayan et al., 2006). Substituting Oatrim for shortening in a cake decreased the batter viscosity and final baked volume, although addition up to 20% did not affect quality (Lee et al., 2005).

To obtain a better understanding of the influence of RS on bubble stability in the raw batters, the specific gravity was calculated and related to the number of air bubbles incorporated into a cake batter. Higher specific gravity values indicate less incorporation of air bubbles. Results show that specific gravity values decrease slightly with increased RS content (Table 2). According to these results, the decrease in raw batter viscosity due to the increase in RS cannot be associated with a decrease in the number of air bubbles. However, it is also important to consider that the specific gravity of batter measures the total air-holding capacity but gives little information about bubble size or dispersion (Pierce and Walker, 1987). In this sense, the inclusion of RS may have affected the size of the initial nuclei and their subsequent coalescence.

3.3. Mechanical spectra of the raw batter

For all the muffin batters, with different concentrations of RS, the mechanical spectra (or evolution of the viscoelastic functions with frequency) at 25ºC showed the existence of soft gels with G’ values slightly higher than G'' and both moduli significantly frequency dependent within the frequency range studied (Figure 3).

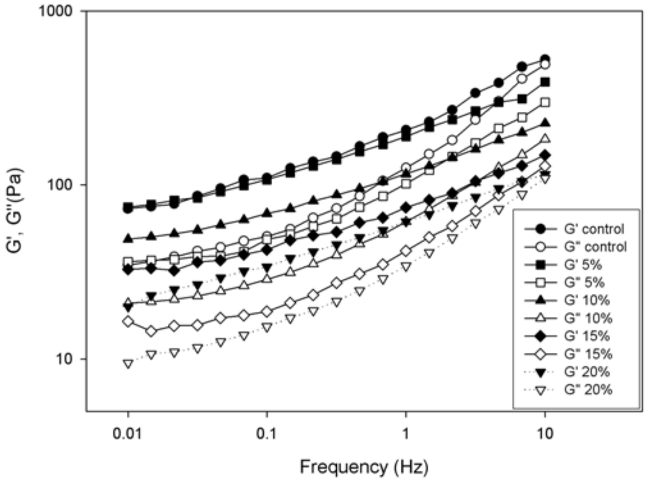

Figure 3. Influence of RS level in the muffin batters on the frequency dependence of the elastic modulus G′ (solid symbols) and the viscous modulus G″ (open symbols) at 25ºC. Shear stress wave amplitude: 0.1 Pa.

The increase in RS content produced a (slight) decrease in the values of both G' and G'' and no changes in the loss tangent (tg δ=G''/G') values were found (Figure 4).

These results indicate a (slight) decrease in the degree of structuring of the system with the addition of RS, but without a significant effect on the type of structuring attributed to the proportional contribution of the elastic and viscous components.

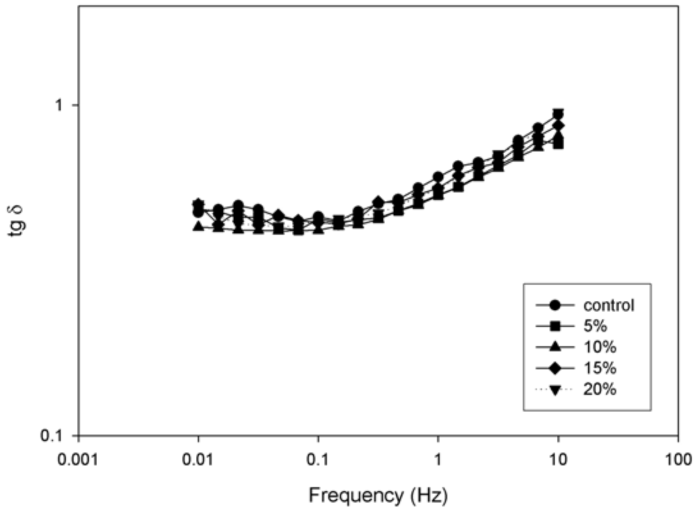

Figure 4. Influence of RS level in the muffin batters on the frequency dependence of the loss tangent values (tg δ) at 25ºC. Shear stress wave amplitude: 0.1 Pa

This result agrees with the flow property results. Other studies have shown a decrease in consistency and in viscoelastic functions when wheat flour was partially replaced with either wheat starch or modified corn starch in batter systems for covering food items; the effect was attributed to the dilution of the wheat flour proteins (Sanz et al., 2005). Similarly, a higher protein content in different types of wheat flour at room temperature has been associated with higher values of G' and G'' (Navickis et al., 1982).

3.4. Viscoelastic and flow properties during heating

In addition to the properties of the raw muffin batter, the structural changes that occur during heating in the oven are also determining factors in bubble formation and stability and in the final baked texture (Shelke et al., 1990). To simulate the structural changes in the muffin batter during baking, the linear viscoelastic properties were studied during the application of a temperature sweep from 25 to 85ºC (maximum temperature achieved by the thermostatic bath of the rheometer). The evolution of G' and G'' upon

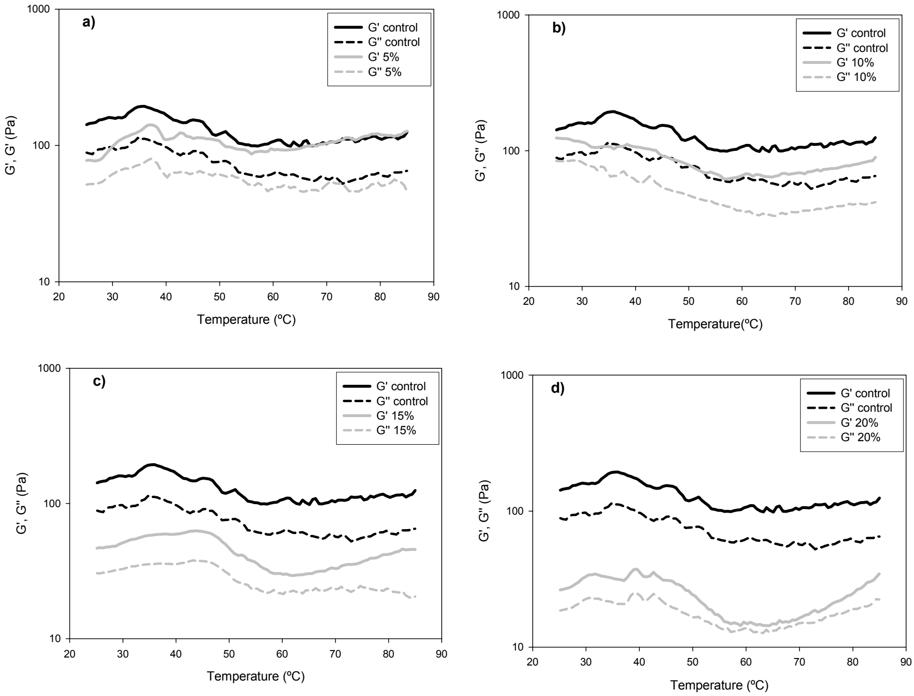

Figure 5. Influence of RS level in the muffin batters on the evolution of G' (solid symbols) and G'' (open symbols) with temperature. Heating rate: 0.017ºC/s. Strain wave amplitude: 0.0007 (control, 5% and 10% RS) and 0.001 (15% and 20% RS). Frequency: 1 Hz. (a) control versus 5%; (b) control versus 10%; (c) control versus 15%; (d) control versus 20%.

Throughout the temperature range, increasing amounts of RS to the batters decreased the value of both viscoelastic moduli. Initially, in the 25 to 35-40ºC temperature range, both viscoelastic moduli showed a very slight tendency to increase. This trend was also found by Ngo and Taranto (1986) and was attributed to protein-protein interactions. From 35-40ºC to around 55ºC, a decrease in both moduli was found. These results agree with previous observations in cake batters by other authors (Lee et al., 2005; Ngo and Taranto, 1986). In this temperature range CO_2 is formed in the batters, diffused into occluded air bubbles and expanded, producing a decrease in the density of the batter.

No starch gelatinization was observed during the temperature sweep. Lin et al. (1994) found the starch gelatinization at 90.6ºC by DSC technique in a yellow layer cake, this was attributed to the high concentration of sugar, which is known to raise the gelatinization temperature of starch. To verify this, evolution of batter viscosity during heating was study on control and 20% RS batters (Figure 6).

Viscosity remained almost unchanged within the interval 25-85ºC in both control and 20% RS samples; however, a dramatic increase in viscosity was observed in the control batter at approximately 87ºC, this increase could be attributed to starch gelatinization onset. On the other hand, in 20% RS batter this increase was not observed, probably because the flour amount in this sample was lower (6% flour), and starch gelatinization would further difficult to record.

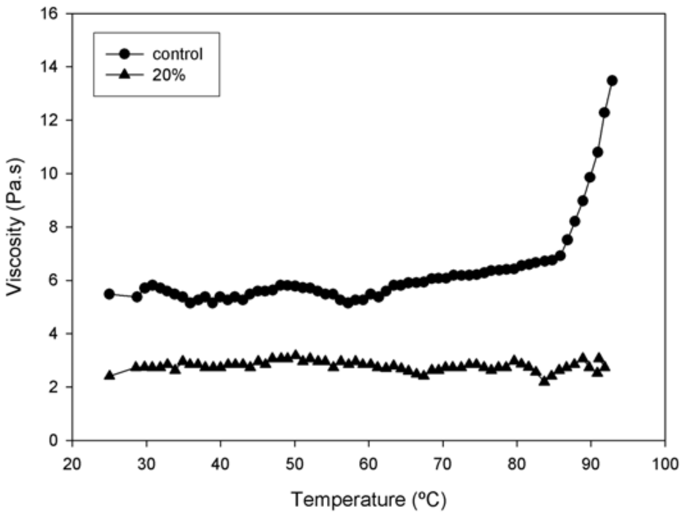

Figure 6. Evolution of viscosity during heating. Control sample (no RS added) (circles), and 20% RS sample (triangles).

These results are in agreement with Shelke et al. (1990) who found that further increase in sugar content (flour weight basis) increased the onset gelatinization temperature.

A difference in the evolution of tg δ with temperature was found for different RS contents in the batters (Figure 7).

While a slight decrease in tg δ values was registered in the control and low RS-content samples in the temperature range studied, samples with 15 and 20% RS, especially from 50ºC to 70ºC, showed an increase in the values of this parameter, which is interpreted as a decrease in the elastic contribution of the system.

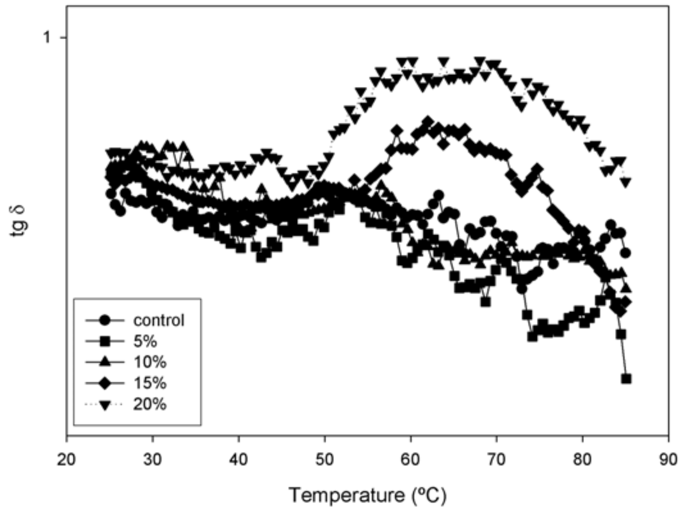

Figure 7. Influence of RS level in the muffin batters on the evolution of loss tangent values (tg δ) with temperature. Heating rate: 0.017ºC/s. Strain wave amplitude: 0.0007 (control, 5% and 10% RS) and 0.001 (15% and 20% RS). Frequency: 1 Hz.

Lower batter viscosity during heating has been associated with a decrease in end product volume (Shelke et al., 1990). Higher viscosities during the heating process prevent coalescence, migration and loss of air cells before the batter sets. Higher viscosities during heating would give the batters a greater capacity to retain the expanding air nuclei and resist the settling of starch granules, thereby improving both cake volume and crumb grain.

3.5. Mechanical spectra at 85ºC

The mechanical spectra obtained at the end of the temperature sweep (85ºC) are shown in Figure 8.

In agreement with the results found in the temperature sweep, the increase in the RS content lowered the values of both viscoelastic functions. In addition, the tg δ values clearly became progressively closer to 1 as the RS content of the muffin batter increased (Figure 9), reflecting a decrease in elastic contribution to the viscoelastic behaviour of the system (more like a fluid). Since the wheat flour content was reduced proportionately as the RS was incorporated into the muffin batter, the effects described may be attributed to the progressive decrease in the structuring effect of starch and wheat protein in the final muffin. It should be pointed out that at the highest RS level (20%), only 6% of wheat flour was present in the system.

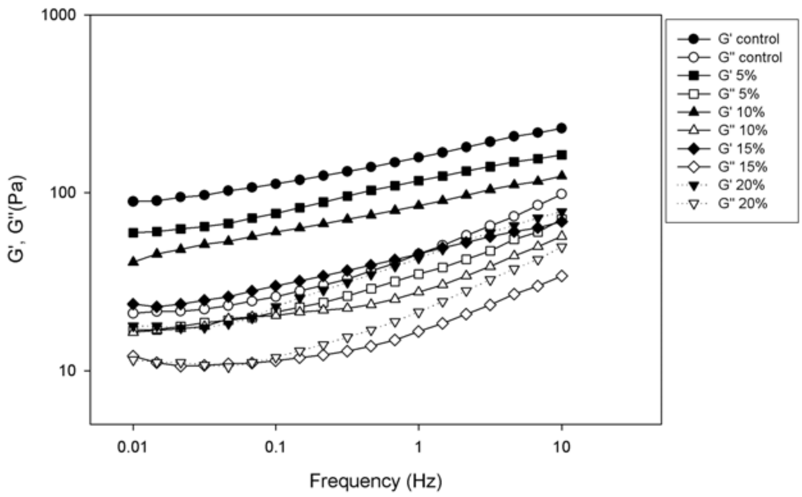

Figure 8. Influence of RS level in the muffin batters on the frequency dependence of the elastic modulus G′ (filled symbols) and the viscous modulus G″ (open symbols) at 85ºC. Shear stress wave amplitude: 0.5 Pa (control), 0.4 Pa (5, 10 and 15%), 0.2 Pa (20%).

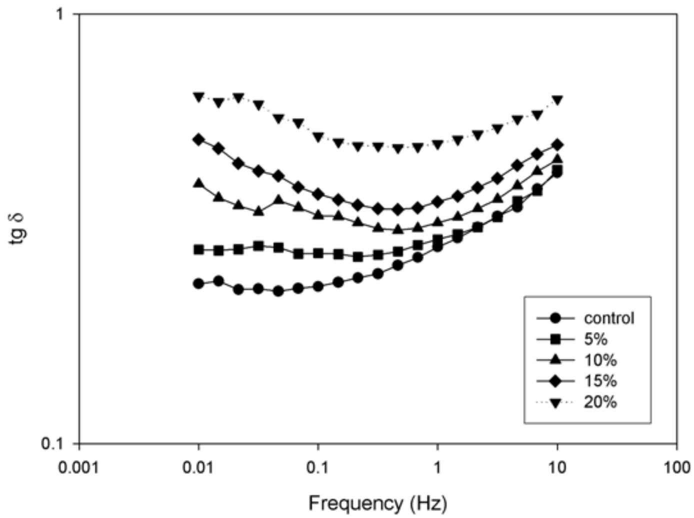

Figure 9 Influence of RS level in the muffin batters on the frequency dependence of the loss tangent values (tg δ) at 85ºC. Shear stress wave amplitude: 0.5 Pa (control), 0.4 Pa (5, 10 and 15%), 0.2 Pa (20%).

CONCLUSIONS

Amounts of RS under 10% by weight of the total formulation hardly influenced the muffin height or the number and area of gas cells in the crumb, which are commonly taken as quality indices. Further increases in the RS content decreased these parameters significantly. The study by SAOS of the rheological properties of the batters during heating reveals a decrease in the elastic properties of the muffin batter upon increasing the level of RS, which could be related to the decrease in the structural elements provided by wheat flour. The flow and linear viscoelastic properties of the muffin batters at 25ºC indicate a decrease in the structure complexity with the increase in RS. However, the specific gravity values did not reveal lower bubble retention capacity of the raw batter in the presence of RS.

Strategies to increase baking performance in the presence of high levels of RS may be mainly directed to incorporating extra ingredients into the formula that are likely to increase the elastic properties of the muffin batter during the heating process, by raising the protein level, for example**.** More research will be needed to verify this statement.

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CAPÍTULO 3

TEXTURAL AND COLOUR CHANGES DURING STORAGE AND SENSORY SHELF LIFE OF MUFFINS CONTAINING RESISTANT STARCH

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Abstract

The effect on baked muffins of progressively replacing wheat flour with resistant starch (RS) (26/0, 21/5, 16/10, 11/15 and 6/20) was studied. In this study, texture profile analysis (TPA) and the elastic recovery test were used to evaluate the effects of RS on the textural properties of fresh and stored muffins (from 0 to 16 days). Textural parameter values decreased with the increase of RS; springiness and cohesiveness reflected better the textural differences for fresh muffins. Changes in textural parameter values with storage time were smaller at higher RS levels. Survival analysis methodology was used to estimate the changes in muffin shelf life. Shelf life time of control muffin is higher than 20%RS muffin for 25% consumer rejection but this behavior is the opposite for 50% consumer rejection.

Keywords: Resistant starch; Muffins; Texture; TPA; Elastic recovery; Shelf life; Survival analysis.

1. INTRODUCTION

Resistant starch (RS) became available commercially some years ago as a food ingredient with a nutritional label listing as dietary fibre (DF). There is no globally agreed definition of DF. One of the latest definitions is: "DF is the edible parts of plants that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine" (De Vries, 2003). RS has been defined as the sum of starch and the products of starch degradation not absorbed in the small intestine of healthy individuals (Asp and Björck, 1992).

It is well-known and documented that the physiological effects of RS include reducing the glycemic response, acting as a functional prebiotic for some probiotic microoorganisms and increasing the production of short chain fatty acids in the large intestine, but RS is also important in the diet because of its interactions with other dietary components, including not only macronutrients such as fats and protein but also micronutrients such as minerals (Asp, Van Amelsvoort and Hauvast, 1996; Brown, 2004; Kendall, Emam, Augustin and Jenkins, 2004; Nugent, 2005). Also, as a functional food ingredient, its low water-holding capacity provides good handling properties during processing (Sajilata, Shinghai and Kulkarni, 2006). RS appears to possess a unique combination of physiological and functional properties compared to traditional types of fibre, which are generally associated with a coarser texture.

The mean DF intake in Europe is 20 g/d and the mean RS intake in Europe is likely to be low, about 4.1 g/d (Asp et al., 1996). One way to ensure that the general population receives adequate amounts of fibre in the diet is to fortify food that would not normally be associated with fibre fortification but is often eaten as snacks, or muffins or cakes that would normally be consumed for breakfast.

Several dietary fibres have been employed to produce high fibre content muffins and cakes. Peach dietary fibre (0-10%) has been added to muffins (Grigelmo-Miguel, Carreras-Boladeras and Martín-Belloso, 2001); Polizzoto, Tinsley, Weber and Berry (1983) and Shafer and Zabik (1978) studied the effect of different dietary fibre sources (α-cellulose, corn bran, oat hulls, rice bran, soy bran, wheat bran and oat bran) in muffins and layer cakes respectively; isolated fibres from wheat, pineapple and field beans seed hull have been included (5% w/w) in a sponge cake and its sensory and physical properties evaluated (Sreenath, Sudarshanakrishna, Prasad and Santhanam, 1996); while Chen, Rubenthaler, Leung and Baranowski (1988) compared apple fibre with wheat and oat bran to evaluate the chemical and physical properties and their effects on muffins.

Texture is one of the main characteristics of bakery products that can be affected by the addition of DF; it can be determined by instrumental or sensory methods. Instrumental methods offer some advantage over sensory analysis because they are rapid and objective. Baeva, Panchev and Terzieva (2000) made a study of texture (sensory and instrumental) to compare normal and energy reduced sponge cakes; Sahi and Alava (2003) studied the crumb structure of sponge cakes to evaluate the effect of different emulsifiers; texture profile analysis of cake crumb was performed by Sing Gujral, Rosell, Sharma and Singh (2003) to study the effect of sodium lauryl sulphate; and Kamel and Rasper (1988) investigated the effect on cake crumb firmness of preparing reduced-calorie cakes with sorbitol or polydextrose to replace sugar.

Storage stability or the shelf life of baked products could be defined as maintenance the sensory and physical characteristics associated with freshness such as crumb tenderness, compressibility and moistness by preventing alteration associated with staling during storage (Paeschke, 1997; Guy, 1983).

However, sensory methods are the only ones that make it possible to assess consumer acceptance. Consumers expect a product with a soft, spongy, tender crumb, but also a certain degree of resistance, not crumbling easily; these characteristics worsen with storage time and, in general, consumer rejection of the product occurs before any microbiological spoilage makes it unsuitable for human consumption (Hough, Langohr, Gómez and Curia, 2003). Different methods may be used to determine the sensory shelf life of a food product using consumer data. In the failure cut-off point method, shelf life is determined as the time when the first significant change in overall acceptability is detected. At this time, consumers detect a change in the sensory characteristics of the product with respect to the fresh product. However, this does not mean that consumers would refuse to consume the product Giménez et al. (2007). In order to estimate sensory shelf life based on consumer rejection of a food product, survival analysis can be applied. This methodology focuses on the shelf life risk of the consumer's rejecting the product. Survival analysis has been used to estimate the shelf life of some baked products (Gámbaro, Fiszman, Giménez, Varela and Salvador, 2004; Gámbaro, Giménez and Varela, 2005).

The objectives of this study are to compare the influence of replacing increasing proportions of wheat flour with four different levels of RS on the textural properties of the muffins, freshly baked and stored for two weeks, and to assess the sensory shelf life of the muffins containing resistant starch.

2. MATERIALS AND METHODS

2.1. Batter and muffin preparation

Five formulations were prepared using the same quantity of all the ingredients except the flour and RS, which were 26/0, 21/5, 16/10, 11/15 and 6/20 per cent respectively. The batter formulation (expressed as a percentage of weight) consisted of wheat flour (Harinera Vilafranquina, S.A., Teruel, Spain) (composition according to the miller: 14.5% moisture, 10.1% protein); resistant starch (HI-MAIZE 260, National Starch Food Innovation, Manchester, United Kingdom) (composition data provided by the supplier: 12% moisture, 63.9% dietary fibre), sugar (26%) (Azucarera Ebro, Madrid, Spain); liquid pasteurized egg white (14%) and liquid pasteurized yolk (7%) (Ovocity, Llombay, Spain); full-fat milk (13%) (Puleva Food, Granada, Spain); refined sunflower oil (12%) (local supermarket), sodium bicarbonate (1.03%), citric acid (0.79%) and grated lemon peel (0.18%). The egg white was whipped in a mixer (Kenwood Major Classic, UK) for 2 min at speed 7 (maximum). Sugar was then added and mixed in for 30 s at speed 7. Egg yolk, citric acid and half of the milk were added and mixed in at speed 3 for 1 min. Wheat flour RS, sodium bicarbonate and grated lemon peel were added and mixed in at speed 3 for 1 min. Oil and the rest of the milk were added and mixed in at speed 4 for 3 min. The batter was placed in an automatic dosing unit (positive displacement pumps, output shaft speed=109 r.p.m., output shaft torque=7.6 N.m.) (Edhard Corp., Hackettstown, USA), and each paper muffin cup (50-mm diameter) was filled with 40.5 g of batter. The muffins were baked in a conventional oven for 6 min at 225 ºC and for a further 6 min at 175 ºC. The oven and oven trays were always the same, the trays were placed at the same level in the oven and the number of muffins baked was always the same. The muffins from each formulation and for each storage time were prepared twice, on different days, with twenty-four muffins in each batch.

After cooling, the muffins were packed in polyethylene bags that were heat-sealed and stored in an environmental chamber at room temperature (20 ± 2 ºC). The muffin samples were evaluated on days 0, 2, 4, 7, 9, 11, 14 and 16.

2.2. Measurement of colour

The instrumental measurement of the muffin colour was carried out with a Hunter Labscan II colorimeter, and the results were expressed in accordance with the CIELAB system with reference to illuminant D65 and a visual angle of 10°. The measurements were performed through a 6.4-mm-diameter diaphragm containing an optical glass. The parameters determined were L* (L* = 0 [black] and L* = 100 [white]), a* (–a* = greenness and +a* = redness), b* (–b* = blueness and +b* = yellowness), C* chroma (saturation) and H* hue, as defined by the following equations:

$$C^* = \left(a^{*2} + b^{*2}\right) \qquad H^* = \arctan\left(b^* / a^*\right)$$

The total colour difference (ΔE*) between the control muffin and the muffins with RS was calculated as follows:

$$\Delta E^* = \left((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \right)^{1/2}$$

The values used to determine if the total colour difference was visually obvious were the following (Francis and Clydesdale, 1975).

$\Delta E^* < 1$; colour differences are not obvious for the human eye.
$1 < \Delta E^* < 3$; colour differences are not appreciative by the human eye.
$\Delta E^* > 3$; colour differences are obvious for the human eye.

Three muffins of each formulation were measured on day 0. Each muffin was cut in two halves to measure the crumb colour, and measurements were made in each muffin. All the measurements were made by placing the sample directly on the colorimeter diaphragm.

2.3. Instrumental texture measurements

Instrumental parameters were measured with a TA-XT.plus Texture Analyzer using the Texture Exponent software (version 2.0.7.0. Stable Microsystems, Godalming, UK). Six muffins per formulation and storage time were studied in each textural test. All formulations were measured in duplicate (two different preparations in different days).

2.3.1. Texture profile analysis (TPA)

2.5-cm sided cubes of muffin crumb were evaluated after removing the upper and lower ends. The test speed was 1 mm s-1 with a strain of 50 %

of the original cube height and a 5-s interval between compression cycles. A trigger force of 5 g was selected. The compression was performed using a 75- mm diameter aluminium plate (P/75). The cubes were compressed twice to give a TPA from which the three primary textural parameters (Pons and Fiszman, 1996) were obtained: hardness (the peak force during the first compression cycle), springiness (the height that the food recovers during the time that elapses between the end of the first bite and the start of the second bite) and cohesiveness (the ratio of the positive force area during the second compression portion to the positive force area during the first compression), as well as resilience (area during the withdrawal of the first compression divided by the area of the first compression.

2.3.2. Elastic recovery test

Elastic recovery was measured according to the Standard Procedure for Muffin Firmness and Elasticity (a relaxation test derivative of the Novo Nordisk modified version of the AACC method 74-09) (AACC, 2000). The percentage of recovery or elastic recovery was measured by compressing a 2.5-cm thick, 2.5-cm diameter cylinder of muffin crumb with the upper and lower ends removed at a test speed of 7.5 mm s-1 and a strain of 50% of the original height for 10 s, after which the probe was removed at a speed of 10 mm s-1. The compression was performed using a 75-mm diameter aluminium plate (P/75). The elastic recovery was measured as:

$$\frac{F10}{F\max} \times 100 = \% recovery$$

where *Fmax* is the maximum force and *F10* is the force after 10 seconds.

2.4. Sensory analysis

Testing was carried out in a sensory laboratory equipped with individual booths (ISO, 1988). Consumers were recruited among workers from the Instituto de Agroquímica y Tecnología de Alimentos, Valencia, Spain. Forty persons, 22-60 years old, approximately half female, half male, who consumed muffins frequently, were used for the study. The testing was carried out in two sessions. At each session the consumers received a muffin from each of the different storage times of two types of muffin (control and 20% RS).

For each sample, the consumers answered yes or no to the question "Would you normally consume this product?" (Hough et al., 2003; Gímenez et al., 2007). These answers (yes or no) were used to calculate the sensory shelf life of the muffins using survival analysis methodology.

Data acquisition and analysis was performed using Compusense® *five* release 4.6 software (Compusense Inc., Guelph, Ont., Canada)

2.5 Statistical analysis

Survival analysis methodology was used to estimate shelf-life, using the results obtained from consumers when asked if they would normally consume the samples, a method recently introduced by Hough et al. (2003). Its key concept is to focus the shelf-life hazard on the consumer rejecting the product rather than on the deterioration. A random variable T is defined as the storage time at which the consumer rejects the sample; the survival function S(t) can be defined as the probability of a consumer accepting a product beyond time t, so S(t)= P(T>t). Alternatively, the cumulative distribution function, F(t)= 1 – S(t), can be defined as the probability of a consumer rejecting a product before time t, that is F(t)= P(T≤t). Usually, survival times are not normally distributed and models such as Weibull distribution for T are chosen. The survival function is given by:

$$S(t) = S_{sev}\left(\frac{\ln(t) - \mu}{\sigma}\right)$$

where μ and σ are the model's parameters.

The probability of a consumer rejecting a product, F(t)= P(T≤t), must be chosen. 25% and 50% rejection probabilities were chosen. These percentages have been used to estimate the shelf life of several foods (Gacula and Singh, 1984; Cardelli and Labuza, 2001; Gámbaro et al., 2001; Varela, Salvador and Fiszman, 2005). The SPLIDA software package for S-PLUS (Insightful Corporation, Seattle, USA) was used to calculate the survival curves.

An analysis of variance (ANOVA) was performed to study the effect of the increasing replacement of wheat flour by different levels of RS. Least significant differences were calculated by Fisher's test. These analyses were performed using SPSS for Windows Version 12 (SPSS Inc., USA).

3. RESULTS AND DISCUSSION

3.1. Influence of Resistant Starch.

3.1.1. Colour analysis

The variation in the colour parameters (L*, a*, b*,C*, H*) and ΔE* due to addition of RS is shown in Table 1.

Table 1. Color parameter values of muffins at different RS concentrations.

	L*	a*	b*	C*	H*	ΔE*
Control	75.9a (2.3)	0.06ab (0.08)	24.0ab (0.4)	24.0ab (0.4)	89.9a (0.3)	
5%	80.1a (1.0)	-0.29a (0.18)	25.3a (0.7)	25.3a (0.7)	90.7a (0.4)	2.44
10%	77.7a (0.6)	-0.02ab (0.14)	22.5c (0.8)	22.5c (0.8)	90.0a (0.3)	2.34
15%	79.7a (1.3)	-0.11b (0.14)	23.3bc (0.8)	23.3bc (0.8)	89.8a (0.5)	3.07
20%	77.1a (4.1)	-0.16ab (0.28)	20.4d (0.6)	20.4d (0.6)	90.5a (0.6)	4.49

Values in parentheses are standard deviations.

Means in the same column without a common lower-letter differ ($p < 0.05$) according to the Tukey multiple range test.

The higher the concentration of RS, the redness, the yellowness and consequently the chroma of muffins decreased. The "white" colour of the RS incorporated acted as diluting the pigmented elements of the formulation. For the same reason, the brightness and the hue values increased with the RS concentration.

In order to study the total colour differences between muffins in relation to RS concentration, the values of ΔE* were calculated. The reference taken in each case was the colour of the control muffin (day 0). The value of ΔE* (Table 1) increased as the concentration of RS increased. At 5% and 10% RS the colour differences were not appreciative by the human eye (1< ΔE*<3). At 15% and 20% RS the colour differences are obvious for the human eye: the samples were less yellowish and less colourfulness.

3.1.2. Texture profile analysis

A prior study was performed to determine the compression percentage that would discriminate adequately between the differences among the samples. TPA was carried out at 50% of compression; this value has been used in other studies (Grigelmo-Miguel et al., 2001, Kim, Yeom, Lim and Lim, 2001; Singh Gujral et al., 2003; Lee, Kim and Inglett 2005), although other compression values such as 30% have been reported (Khouryied, Aramouni and Herald, 2005), 35% (Sahi and Alava, 2003), 40% (Baik, Marcotte and Castaigne, 2000) or 60% (Arunepanlop, Morr, Karleskind and Laye, 1996), indicating that there is not a clear criterion for this experimental condition. Although chewiness was calculated the data are not shown because its behaviour was the same as for hardness.The TPA curves are shown in Figure 1.

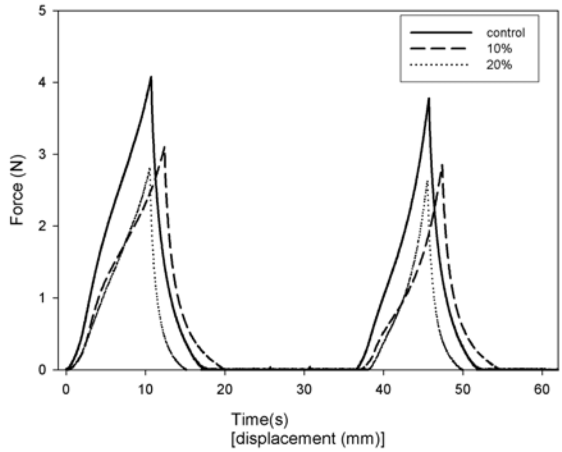

Figure 1. TPA curves for fresh muffins at different RS concentrations

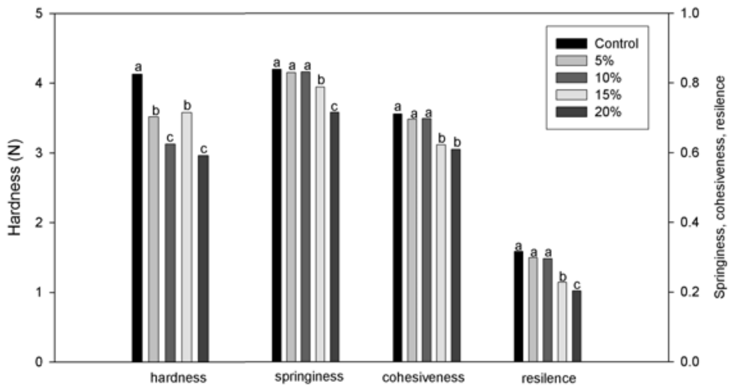

Figure 2. Effect of different RS concentrations on TPA parameter values for fresh muffins

The "hardness" values (Figure 2) of the muffins with RS were significantly lower (P<0.05) than those of the control muffins and although the decrease in hardness was not linear with wheat replacement, the lowest hardness value was for the highest concentration of RS (20%). The "springiness" value is shown in Figure 2. Springiness decreased as RS rose; this decrease was clear and significant from 15% of RS. At lower concentrations of RS (5% and 10%) there were no significant differences compared to the control.

The "cohesiveness" parameter (Figure 2) decreased with the addition of RS; at 5 and 10% the decrease in this parameter was so slight that there were no significant differences compared to the control muffin, at higher concentrations of RS (15 and 20%) the cohesiveness value decreased significantly but there were no differences between these two formulations. The lower cohesiveness values would indicate that less energy was required for the second compression.

The addition of RS produced a very slight decrease in the "resilience" parameter (Figure 2) at 5 and 10% RS, but the decrease was not significant ($P<0.05$). At greater RS concentrations (15 and 20%) the resilience value decreased significantly. The pattern of behaviour was the same as for the springiness parameter.

These results did not agree with the study by Grigelmo-Miguel et al. (2001), who reported that adding peach dietary fibre to muffins increased their hardness although their springiness and cohesiveness did not differ from those of muffins without dietary fibre.

A possible explanation of the decrease in resilience and springiness with the addition of RS is that the product matrix becomes denser. At the higher RS level the number and area of the gas cells (Baixauli, Sanz, Salvador and Fiszman, 2007) and the height of the final baked muffins decreased (4.70 cm for control; 4.50 cm for 10% RS and 3.84 cm for 20% RS), and therefore, the samples were less able to recover after deformation. In fact, a volume reduction in bread with β-glucan addition was reported attributable to gluten dilution, resulting in an underdeveloped gluten network; this would limit the extend of dough inflation and gas cell stability during proving, with a reduced loaf volume (Symons and Brennan, 2004). Similar results were found by Tudorica, Kuri and Brennan, (2002) in dietary fiber enriched pasta: significantly reduced firmness and elasticity values were obtained with fiber addition; this reduction was related to the disruptive behaviour of the fiber on the protein-starch binding during pasta matrix formation.

3.1.3. Elastic recovery

The elastic recovery was calculated from the relaxation curves shown in Figure 3.

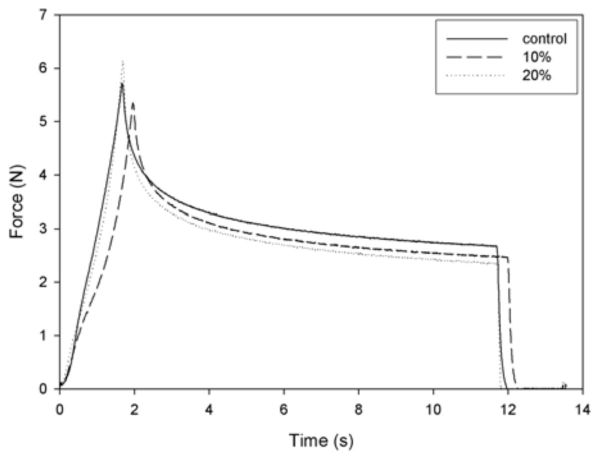

Figure 3. Elastic recovery curves for fresh muffins with different RS concentrations

The elastic recovery results on day 0 are shown in Table 2.

Table 2. Elastic recovery parameter values of muffins at different storage times.

	days							
	0	2	4	7	9	11	14	16
Control	47.6Aa (0.8)	42.4b (0.5)	39.4c (0.7)	37.6d (0.8)	36.5efg (0.9)	36.8ef (0.3)	36.3efg (0.7)	36.1eg (0.5)
5%	47.9Aa (0.9)	42.2b (0.4)	38.7cd (0.5)	38.6cd (0.8)	38.1cdf (0.5)	37.5df (0.4)	35.6g (1.4)	35.1g (1.3)
10%	47.5Aa (0.6)	43.6b (0.3)	39.7c (0.2)	39.3c (0.5)	39.4c (0.3)	38.1d (0.3)	37.5e (0.6)	37.1e (0.6)
15%	43.8Ba (0.4)	41.7b (0.8)	38.8c (0.4)	38.6c (0.4)	37.2dg (0.3)	39.3e (0.2)	37.7fg (0.4)	37.4dfg (0.3)
20%	40.9Ca (0.7)	38.9b (0.7)	38.3cdf (0.4)	38.2cdef (0.7)	37.9cdef (0.3)	37.7defg (0.3)	37.9cdef (0.5)	37.3eg 0.4

Values in parentheses are standard deviations.

Means in the same row without a common lower-letter differ ($p < 0.05$) according to the least significant difference multiple range test.

For fresh muffins (day=0), means in the same column without a common capital-letter differ ($p < 0.05$) according to the least significant difference multiple range test

The values at 5% and 10 % RS were the same as for the control muffins, but at higher concentration of RS this value decreased significantly. The results are in agreement with Singh, Rockall, Martin, Chung and Lookhart (2006), who studied the relaxation behaviour of some foods. They reported that angel cakes and pound cakes showed a *% recovery* in the range of 50 to 40 and reported that this may be due to the cross-linked protein structure formed during the baking process. The elastic recovery value indicates the elastic and the viscous component, which are correlated with the gliadin and glutenin fractions present in wheat gluten protein.

Similar studies were carried out by Kamel el al. (1988) to examine the effect of emulsifiers on the texture of reduced-calorie cakes, which showed that the elastic recovery values consistently fell when higher concentrations of emulsifiers were applied, and by Shearer and Davies (2005) to evaluate changes to freshly baked muffins with flaxseed oil or full-fat flaxseed meal. Freshly baked muffins prepared with flaxseed meal were less elastic (ability of a muffin to relax while compressed) than the control muffins.

The results of elastic recovery were in agreement of TPA data: muffins containing higher RS concentration showed a less cohesive and elastic structure.

3.2. Textural properties during storage

The textural properties of the muffins were evaluated over a 16-day storage period. This study reflects the textural changes in the samples prepared with different RS levels that took place during storage.

As can be observed in Figure 4 (a), the value for the "hardness" parameter of the control muffin tripled over 16 days of storage. The muffins with 5, 10 and 15% RS behaved in the same way. The muffins with 20%RS were softer than the control muffins on day 0 and the evolution of their textural parameters over the storage time was different. Muffins with 20% RS were always softer than the other muffins, as their hardness value doubled over the 16 days of storage. In this case, 20% RS proved effective for obtaining softer muffins than the control samples and, as can be observed in Figure 4 (a), it diminished the hardening of the muffins during storage. These results are in agreement with Yue and Waring (1998) who have shown that muffins formulated with 40% TDF (Total Dietary Fibre) resistant starch remained softer than the control during a 2-week storage period.

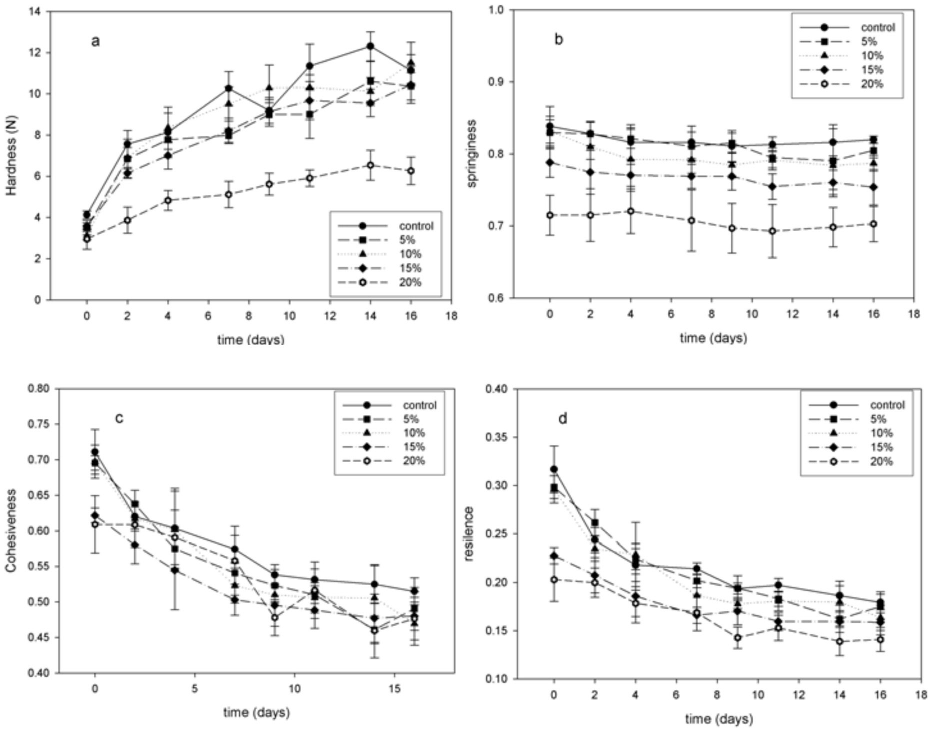

Figure 4. TPA parameter values of muffins with different RS concentrations as a function of storage time. Hardness (a), Springiness (b), Cohesiveness (c) and Resilience (d)

The "springiness" parameter did not provide information, as can be observed in Figure 4 (b). Non-significant differences with storage time were found, although the values were lower in the presence of RS.

The "cohesiveness" showed a significant fall over the storage period (Figure 4 (c)), although this decrease was lower for 15% and 20% RS samples. Consequently, higher concentrations of RS were effective in preventing a sharper drop in this parameter.

The same tendency was shown by the "resilience" (Figure 4 (d)) and confirmed by "elastic recovery" values (Table 1).

3.3. Sensory analysis

Percentage rejection versus storage time was then plotted (Figure 5) using the Weibull distribution.

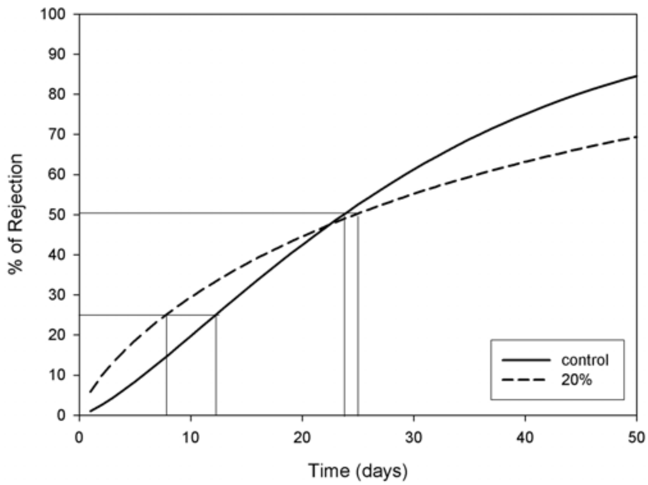

Figure 5. Percentage of consumers rejecting control and 20% RS muffins vs. storage time

The shapes of the curves were different for the two different levels of RS chosen (control and 20%); as can be observed in Figure 5. During the early days of storage the percentage rejection was lower for the control muffins than for the 20% RS muffins, probably because the controls reminded the consumers more of a typical muffin. As time went on, however, the reverse was found, as the percentage rejection was higher for the control muffins than for the 20% RS muffins. This could be because, as mentioned above, the texture of the 20% RS muffins changed less over time.

CONCLUSIONS

The addition of RS in muffins produced a softer texture: the samples were less hard, elastic and cohesive reflecting a more tender structure; these effects were more evident at higher concentrations of RS. During a storage period of 16 days the samples with RS remained softer than control samples. These results were confirmed by sensory shelf-life analysis: after 23 days of storage the predicted percentage rejection by consumers for the RS-containing muffins was lower than the control sample.

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CAPÍTULO 4

DISTINCTIVE SENSORY FEATURES INTRODUCED BY RESISTANT STARCH IN BAKED PRODUCTS.

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Abstract

The effect of progressively replacing wheat flour with resistant starch (RS) (0, 5, 10, 15 and 20%) on the sensory properties of baked muffins was studied. Consumer acceptability was evaluated by a hedonic scoring scale and a food action rating scale. Muffins did not differ significantly (p<0.05) in 'taste', 'overall acceptance' and 'consumption intention' but significant differences were found in the 'appearance' and 'texture' attributes. A descriptive sensory analysis was also carried out by a panel of ten trained panellists. The 'cohesiveness', 'typical taste', 'typical odour', 'number of gas cells', 'springiness', and 'chewiness' attribute scores decreased with the addition of RS. Moisture perception increased with the addition of RS despite the decrease in moisture when measured instrumentally; sweetness perception also increased as the RS rose even though all the concentrations had the same concentration of sugar; and a sensation of grittiness appeared that was not detectable in the absence of RS.

Keywords: Resistant starch; Muffins; Consumer acceptability; Descriptive sensory analysis

1. INTRODUCTION

In recent years there has been an increase in the availability of nutritionally functional foods with potential health benefits. The effect of dietary fibre (DF) on promoting health and preventing disease has been an issue of interest since antiquity and has become a subject of renewed research activity in recent years (Shadidi, 2000).

Starch, which is the major dietary source of carbohydrates, is the most abundant storage polysaccharide in plants. The relatively recent recognition of incomplete digestion and absorption of starch in the small intestine as a normal phenomenon has aroused interest in non-digestible starch fractions (Englyst, Kingman and Cummings, 1992). These are called 'resistant starch' and have been defined as the sum of starch and the products of starch degradation not absorbed in the small intestine of healthy individuals (Asp and Bjorck, 1992).

Several studies have shown resistant starch (RS) to have physiological functions similar to those of dietary fibre (Asp, 1994; Nugent, 2005), such as prevention of colonic cancer (Leu, Hu and Young, 2002), control of blood glucose levels (Reader, Johnson, Hollander and Franz, 1997) and hypocholesterolemic effects (Martínez-Flores, Yoon-Kil-Chang, Martínez-Bustos and Sgarbieri, 2004). Food applications of resistant starch (RS) are of interest to product developers and nutritionists for two reasons, the first being the above-mentioned potential physiological benefits and the second the high final quality of the products, which is not attainable with traditional insoluble fibres. The physical properties of RS, particularly its low water-holding capacity, make it a functional ingredient that provides good handling and provides and improves texture in the final product (Yue and Waring, 1998). Baixauli, Salvador and

Fiszman (2007) studied the instrumental texture characteristics of muffins with added RS and noted that adding RS to muffins produced a softer texture than without added RS: the samples were less hard, elastic and cohesive, reflecting a more tender structure; these effects were more evident at higher concentrations of RS.

The mean DF intake in Europe is 20 g/d and the mean RS intake in Europe is likely to be low, about 4.1 g/d (Asp, vanAmelsvoort and Hauvast, 1996). The consumers' dietary fibre intake could be increased by eating foods which are naturally high in fibre and also by eating foods with fibre added to them. However, dietary patterns are difficult to change because the consumers' food selection patterns are dominated by sensory preferences in taste and texture. In view of this, processors are engaged in incorporating fibre into various baked products to satisfy consumer needs for increased fibre intake without sacrificing attributes (Fondroy, White and Prusa, 1989).

In order for a novel, nutritionally functional ingredient to be accepted by the food industry and consumers, beneficial physiological effects as well as high organoleptic acceptability need to be demonstrated (Australian National Food Authority, 1994).

The effect of adding other types of fibre on the sensory acceptability of a baked product has been studied by several authors. Grigelmo-Miguel, Carreras-Boladeras and Martín-Belloso (1999) evaluated the sensory characteristics of muffins in which high levels of peach dietary fibre replaced flour; at up to 5% of added peach fibre no significant change in consumer acceptability was found. Fibre-enriched muffins had a good flavour and mouthfeel and were as spongy as traditional muffins, although slightly darker because of the replacement of white flour with peach fibre. Clark and Johnson (2002) studied the sensory acceptability of muffins enriched with lupin kernel fibre; the addition of this fibre did not change the consumer rating of the muffins' appearance significantly, although lower consumer ratings in comparison to the control were seen for 'overall acceptability', 'flavour' and 'texture in mouth'. Ramcharitar, Bradie, Mattfeldt-Beman, Matsuo and Ridley (2005) evaluated the consumer acceptability of muffins with flaxseed on sensory attributes such as 'appearance', 'colour', 'flavour', 'texture', and 'overall acceptability' by hedonic scoring; flaxseed is used in functional foods due to the presence of functional compounds such as α-linolenic acid, lignans, and fibre (28%). These authors found that flaxseed muffins were rated lower than control muffin (0% flaxseed) for all sensory attributes; the flaxseed muffins (11.6% flaxseed) were rated from 'neither like nor dislike' to 'like slightly' for 'overall acceptability'.

Sensory evaluation of food products, especially by consumer panels, has re-emerged as an invaluable science in conjunction with nutritional research and functional food development (Scholtz and Bosman, 2005). Consumer research in the early stages of new product development makes it possible to go farther and deeper into understanding consumer needs, often well beyond what could be understood without them (Van Kleef, Van Trijp and Luning, 2005).

However, sensory evaluation using a trained descriptive panel is also required for a fuller assessment of the effects of fibre use on the wide range of parameters (Meilgaard, Civille and Carr, 1991).

The aim of this work is to study the effects of resistant starch RS on typical muffin attributes using a trained descriptive panel and to evaluate the consumer acceptability of muffins enriched with RS.

2. MATERIALS AND METHODS

2.1 Sample preparation

Five formulations were prepared using the same quantity of all the ingredients except the proportions of flour/RS, which were 26/0 (control), 21/5 (5% RS), 16/10 (10% RS), 11/15 (15% RS) and 6/20 (20% RS). The batter formulation (expressed as a percentage of weight) consisted of wheat flour (Harinera Vilafranquina, S.A., Teruel, Spain) (composition according to the miller: 14.5% moisture, 10.1% protein); resistant starch (HI-MAIZE 260, National Starch Food Innovation, Manchester, United Kingdom) (composition data provided by the supplier: 12% moisture, 63.9% dietary fibre); sugar (26%) (Azucarera Ebro, Madrid, Spain); liquid pasteurized egg white (14%) and liquid pasteurized yolk (7%) (Ovocity, Llombay, Spain); full-fat milk (13%) (Puleva Food, Granada, Spain); refined sunflower oil (12%) (local supermarket); sodium bicarbonate (1.03%); citric acid (0.79%) and freshly grated lemon peel (0.18%). The egg white was whipped in a mixer (Kenwood Major Classic, UK) for 2 min at speed 7 (maximum). Sugar was then added and mixed in for 30 s at speed 7. Egg yolk, citric acid and half of the milk were added and mixed in at speed 3 for 1 min. Wheat flour, RS, sodium bicarbonate and freshly grated lemon peel were added and mixed in at speed 3 for 1 min. Oil and the rest of the milk were added and mixed in at speed 4 for 3 min. The batter was placed in an automatic dosing unit (positive displacement pumps, output shaft speed=109 r.p.m., output shaft torque=7.6 N.m.) (Edhard Corp., Hackettstown, USA), and each paper muffin cup (50-mm diameter) was filled with 40.5 g of batter. The muffins were baked in a conventional oven for 6 min at 225 ºC and for a further 6 min at 175 ºC. The oven and oven trays were always the same, the trays were placed at the same level in the oven and the number of muffins baked was always the same. The muffins from each formulation were prepared twice, on different days, with twenty-four muffins in each batch. After cooling, the muffins were packed in polyethylene bags that were heat-sealed and stored in an environmental chamber at room temperature (20 ± 2 ºC). The muffins were evaluated two days after baking.

2.2. Instrumental Analysis

2.2.1. Moisture Content

The moisture content of the muffins was determined according to AACC Method 44-40 (AACC, 2000). Triplicate tests were conducted for each formulation.

2.2.2. Image analysis

The muffins were cut longitudinally (plane parallel to batter expansion), and images of the freshly cut surface of the crumb were captured using a Hewlett Packard flatbed scanner (HP 4300c, Hewlett Packard, USA). Image processing was performed using Image Pro-Plus 4.5 Media Cybernetics (Media Cybernetics, USA). The images were converted to 8-bit grey scale and segmented separately using a histogram-based segmentation that was defined individually for each image. When good segmentation was achieved, as determined by visual inspection, the cells of the muffins were counted; the pixel-width values for the cell counts were $50\text{-}10^7$. Four muffins per formulation (two muffins per batch) were measured.

2.3. Sensory Evaluation

Testing was carried out in a sensory laboratory equipped with individual booths (AENOR, 1997). The different samples were presented to the consumers on identical trays. Data acquisition was performed using Compusense® *five* release 4.6 software (Compusense Inc., Guelph, Ont., Canada).

2.3.1. Consumer test

Consumers were recruited among employees of the Instituto de Agroquímica y Tecnología de Alimentos, Valencia, Spain. A total of fifty untrained panellists (consumers) aged 22–60, approximately half female, half male, who consumed muffins frequently were used for the study. Each consumer received one muffin of each RS concentration at a single session following a balanced complete block experimental design. The muffins were coded by three-digit random numbers. The muffins were served at room temperature in random order. Water was supplied to clean the consumers' mouths between each sample. For each sample they had to score the 'appearance', 'texture', 'taste' and 'overall acceptance' of the product. A nine-box scale was used for sensory evaluation (9= like extremely; 8= like very much; 7= like moderately; 6= like slightly; 5= neither like nor dislike; 4= dislike slightly; 3= dislike moderately; 2= dislike very much and 1= dislike extremely). Consumers were also asked to complete a nine-box scale FACT food action rating survey (Schutz,

1965) to determine the expected frequency of consumption if the product were available in the marketplace (the FACT scale survey asks how often a food would be eaten). The FACT scale was a nine-box scale labelled as follows: 9= I would eat this at every opportunity; 8= I would eat this very often; 7= I would frequently eat this, 6= I like this and I would eat it now and then; 5= I would eat this if available but would not go out of my way; 4= I don't like this but I would eat it on occasion; 3= I would hardly ever eat this; 2= I would eat this if there were no other food choices; 1= I would eat this only if I were forced to (Ramcharitar et al., 2005). The consumers had to score their consumption intention for each sample.

2.3.2. Descriptive analysis

2.3.2.1. Selection of terms and panel training

A panel of 8 assessors with wide experience in descriptive analysis selected the descriptors using the Check List Method (Moskowitz, 1983; Powers, 1988; Lawless and Heymann, 1998). The selection of descriptors was made over two sessions. Assessors were provided with representative samples and asked to choose the most representative words to describe the samples (Gámbaro, Varela, Giménez, Aldrovandi, Fiszman and Hough, 2002). During the training sessions, the panellists suggested a list of meaningful sensory quality attributes for the product and discussed the definition and evaluation of each attribute. Once the terms had been selected, a consensus about their usage was reached; this implied precisely defining the descriptors and how to evaluate them to quantify attribute intensity, as well as agreeing upon the tasting procedure. The selected descriptors are shown in Table 1. For the descriptor standardization and panel training, three samples of muffins with concentrations between 0% RS (control) and 20% RS were used. 0% and 20% were employed as the samples with extreme characteristics.

Table 1. Descriptive terms and descriptions used in sensory analysis of muffins

ATTRIBUTES	DESCRIPTION
Typical odour (crumb)	Typical muffin odour when the muffin was evaluated just after being cut in half
Number of gas cells	Number of cells that make the crumb appear either dense and compact or light and open
Springiness	Swiftness of return to the initial shape after moderate pressure on the crumb with the middle finger
Chewiness or resistance to mastication	Degree of perceived resistance to chewing a piece of muffin before swallowing
Cohesiveness	Force necessary to crumble a piece of muffin into the palate with the tongue
Moistness	Moistness felt when chewing a piece of muffin
Grittiness	Grittiness felt when chewing a piece of muffin
Taste	Typical muffin taste
Sweetness	Degree of perceived sweetness of the sample

Training involved two stages: in the first, ranking tests of three muffins with different RS concentrations were used by the panellists for each descriptor until the panel was homogeneous in its assessments, with Kendall's *W* coefficient ≥0.7 (Moskowitz, 1983); to complete this stage, ten 20 min sessions were necessary. In the second stage, the panellists used 10 cm unstructured scales to score the selected attributes of the muffins with different RS concentrations and their performance was followed by means of Principal Component Analysis until there were no outliers in the group (King, Hall and Cliff, 2001); completing this stage required fifteen 20 min sessions.

2.3.2.2. Formal assessment

A balanced complete block experimental design was carried out in duplicate to evaluate the samples. The intensities of sensory attributes were scored on a 10 cm unstructured line scale labelled from “low” to “high”. At each session, the samples were randomly selected and served in random order, each on a separate plastic tray, identified with a three digit random code. Panellists were instructed to rinse their mouths with water between sample evaluations.

2.1 Statistical analysis

Principal Component Analysis (PCA) was used to follow panel performance during training. It was conducted for all panellists on their mean scores for each sensory attribute across all the samples.

Analysis of variance (ANOVA) was performed on the consumer and trained sensory panel data using percentage of RS, panellist and their interaction as variation factors. In order to study the differences among the samples, Tukey’s comparison ($p \leq 0.05$) was applied. The analyses were performed using SPSS for Windows Version 12 (SPSS Inc., USA).

3. RESULTS AND DISCUSSION

3.1 Moisture content

The moisture contents of the muffins containing different levels of RS were significantly lower than those of the control muffin (Table 2).

Table 2. Effect of RS on moisture and number of gas cells of muffins

	Moisture	Number of gas cells
Control	22.12 a (0.14)	54 a (5)
5%	21.30 b (0.04)	31 b (0)
10%	20.61 d (0.05)	24 c (2)
15%	21.14 bc (0.06)	26 bc (3)
20%	20.71 cd (0.36)	16 d (3)

Values in parentheses are standard deviations.

[abcd]Means in the same column without a common letter differ ($p < 0.05$) according to the Tukey test.

The moisture content generally decreased with the addition of RS. Grigelmo-Miguel et al. (1999) reported that the addition of other dietary fibres (DF) had the contrary effect: the incorporation of peach DF (levels from 2% to 10%) in muffins increased the moisture percentage with each increment, a fact which they attributed to prevention of water loss during baking because of the water holding capacity of peach DF. The water holding capacity of the RS employed is lower than that of other fibre sources such as oat fibre, cellulose and wheat flour.

3.2 Image analysis

Higher RS concentrations decreased the number of gas cells in the muffins (Table 2). With the addition of RS the distribution of gas cells changed: the number of small cells increased and the number of big cells decreased, although the size of the big cells was greater with the addition of RS. This behaviour can be observed in Figure 1. Cells with a diameter of under three millimetres were considered small gas cells.

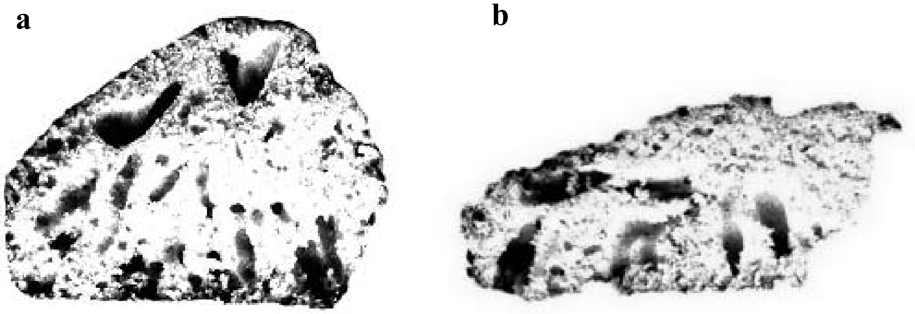

Figure 1. Images of control muffin (a) and 20% RS muffin (b) in grey scale and with the filters applied.

3.3 Consumer evaluation

The mean sensory acceptance scores for the 'appearance', 'texture', 'taste', 'overall acceptance' and 'consumption intention' of muffins with different RS concentrations are presented in Table 3.

Table 3. Consumers' sensory evaluation of muffins containing RS

	Appearance	Texture	Taste	Overall acceptance	Consumption intention
Control	7.3a (1.0)	5.7a (1.8)	6.5 a (1.5)	6.4 a (1.4)	5.7 a (1.4)
5%	7.8a (0.8)	6.4ab (1.6)	6.9 a (1.5)	6.6a (1.6)	6.1a (1.6)
10%	6.0b (1.7)	6.8 b (1.3)	6.8 a (1.4)	6.6a (1.3)	6.2 a (1.3)
15%	5.9 b (1.5)	6.6 ab (1.6)	6.6a (1.4)	6.6 a (1.4)	6.1 a (1.3)
20%	5.6 b (1.5)	6.6 ab (1.9)	6.6 a (1.8)	6.4a (1.9)	6.0a (1.7)

Values in parentheses are standard deviations.

[ab]Means in the same column without a common letter differ ($p < 0.05$) according to the Tukey test

Statistical analysis showed that the muffins did not differ significantly ($p<0.05$) in 'taste', 'overall acceptance' or 'consumption intention'. Although there were no significant differences in the 'overall acceptance' of the samples, this does not mean that there were no differences between the samples but that all the samples were well accepted. With respect to the 'appearance' attribute, no significant differences were encountered between the control and 5% RS, probably due to their external appearance, or between 10, 15 and 20% RS. The scores were lower at higher RS concentrations; this could be related to the height of the final baked muffin, which falls as the RS in the formulation is increased: Baixauli, Sanz, Salvador and Fiszman (2007) measured 4.70 cm for control, 4.59 cm for 5% RS, 4.50 cm for 10% RS, 4.12 cm for 15% RS and 3.84 cm for 20% RS. Ramcharitar et al. (2005) reported that the appearance score for flaxseed muffins was lower than for the control (0% flax), which they attributed to some consumers being able to distinguish the colour of the flax muffin from that of the control muffin.

RS muffins were rated higher than the control for the 'texture' attribute, demonstrating that the addition of RS improved the texture. These results are in agreement with Yue and Waring (1998), who found that when RS (RS-2 and RS-3 type resistant starch) was added to cake-like muffins, the RS acted as a texture modifier, imparting a favourable tenderness to the crumb.

On the FACT scale, there were no significant differences between the samples and the likelihood that the consumers would consume this product lay closest to the FACT scale descriptor of “I like this and I would eat it now and then”. Ramcharitar et al. (2005) found that when flaxseed was added to muffins, consumers scored these muffins lower on the FACT scale than the controls.

The significant differences found in the 'appearance' and 'texture' attributes did not reflect an 'overall preference' in any sense. To study these attributes in greater depth and to define the differences, it was considered of interest to perform a test with a trained panel.

3.4 Sensory descriptive analysis

The mean scores given by the trained panellists for the sensory characteristics of the muffins with different concentrations of RS are presented in table 4.

Table 4. Mean values for the sensory parameters that presented significant differences at the percentage of RS added.

% RS	Typical odour	Number of gas cells	Springiness	Chewiness	Moisture	Grittiness	Cohesiveness	Typical taste	Sweetness
0	8.3 a	9.0 a	9.5 a	9.2 a	0.8 a	0.4 a	9.3 a	9.1 a	1.0 a
5	5.2 b	5.5 bc	7.4 b	6.9 b	3.2 b	2.1 b	7.9 b	7.8 b	3.6 b
10	3.0 cd	6.7 b	7.3 b	6.0 b	3.9 b	4.1 c	6.3 c	7.0 b	5.0 c
15	3.5 c	4.7 c	2.8 c	3.5 c	3.8 b	5.8 d	4.4 d	4.9 c	7.0 d
20	1.6 d	2.2 d	0.8 d	1.1 d	7.9 c	8.4 e	0.7 e	1.4 d	8.6 e

[abcde]Different letters indicate significant differences at $p \leq 0.05$ according to the Tukey's test

Figure 2 shows the sensory characteristics of the control, 10%RS and 20%RS muffins.

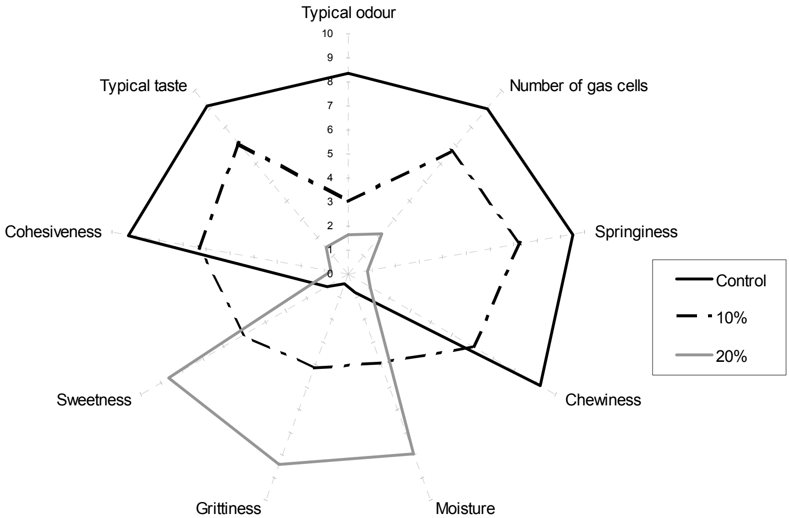

Figure 2. Sensory descriptive analysis. Evolution of sensory attributes when RS was added to the muffins.

There were significant differences for all the descriptors as RS level increased in the samples, six of which ('typical odour', 'number of gas cells', 'springiness', 'chewiness', 'cohesiveness' and 'typical taste') received significantly lower scores compared with the control.

However, the 'grittiness', 'sweetness' and 'moisture' scores rose with the addition of RS. The presence of RS affected the product texture by giving a gritty mouthfeel, so this score ('grittiness') rose with the addition of RS, indicating that the perception of particles of RS can be important as a textural characteristic. This RS has a fine particle size, between 10-15 μm, and despite its small size it was detected by the panellists. Fondroy et al. (1989) found that when an oat straw fibre fraction (fluffy cellulose) was added to a lean white cake the presence of the fibre altered the product by leaving a gritty mouthfeel after swallowing. Imai et al. (1995) reported that concentration, dispersion medium and particle size were all important factors contributing to perceived grittiness and also observed that the perceived grittiness decreased as the viscosity of the dispersion medium increased.

The score for 'sweetness' rose with the addition of RS even though the sugar level was the same for all the formulations. Kanemaru, Harada and Kasahara (2002) studied the effect of soluble acid-modified starch on taste intensity in human subjects using different concentrations of sucrose dissolved in the starch solution and found an increase of sweetness intensity when sucrose was added to soluble starch at 0.25 and 4.0%; they suggested that the taste enhancing effects of soluble starch on sucrose sweetness depend not only on the taste transduction mechanism, but also on the molecular interaction between sucrose and starch.

The panellists' scores for the 'moisture' descriptor rose with the addition of RS, whereas the instrumental measurement of moisture showed that the values fell. Other fibres (cellulose type) may bind the water so tightly that the water is not available as free moisture, thus, the high-fibre product may be perceived as drier in the mouth (Fondroy et al., 1989). Increased moisture sensation was found by Conforti and Smith (1998) when panellists tasted fat-reduced and full-fat muffins: although the full-fat muffin had a lower moisture content, it was perceived as moister than the fat-reduced product. This suggests that in the present case the RS could be acting as a lubricant and that the panellists tended to perceive this phenomenon as an increase in moisture.

CONCLUSIONS

Although RS producers claim that the sensory properties of bakery products are not modified when RS is used, the results obtained in this study demonstrated that some differences do appear. Moisture and sweetness perceptions changed and grittiness appear as a new feature. However, these characteristics did not affect the 'overall acceptance' of these products to consumers.

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HOW INFORMATION ABOUT FIBRE (TRADITIONAL & RESISTANT STARCH) INFLUENCES CONSUMER ACCEPTANCE OF MUFFINS

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Abstract

The influence of information on the fibre content of plain, wholemeal and fibre-enriched (resistant starch) muffins was studied in 102 consumers. Sensory attributes, health and nutrition questions and consumption and purchase intentions were evaluated with and without information about fibre content. Plain muffins scored the same with or without information. Consumers without information gave the wholemeal muffin a low score, but when information was given to the consumers the score increased. However, it would seem that the information was not well understood for fibre-enriched muffins, as although the quantity of fibre was the same for the wholemeal and fibre-enriched muffins, the consumers appear not to have believed it. On grouping the consumers by health consciousness attitudes, when the information was provided the high health consciousness group gave higher ratings but the low health consciousness group gave lower ratings.

Keywords: Information, health consciousness, muffin, fibre, consumer.

1. INTRODUCTION

In recent years there has been an increase in the availability of nutritionally functional foods with potential health benefits. The effect of dietary fibre (DF) on promoting health and preventing disease has been an issue of interest for many years and has become a subject of renewed research (Shadidi, 2000).

The intake of fibre and fibre-containing foods is below recommended levels in all Western countries. The interest in foods with high fibre contents has increased in recent decades and the importance of this food constituent has led to the development of a large market for fibre-rich ingredients and products such as snacks, muffins or types of cake that are normally consumed at breakfast. This way of increasing fibre levels can be useful for ensuring that the population receives adequate amounts of fibre.

Dietary patterns are difficult to change because consumers' food selection patterns are dominated by sensory preferences in taste and texture. It is well-known that consumers often perceive fibre as having a strong flavour, being unpalatable and possessing a coarse texture and dry mouthfeel (Yue and Waring, 1998); dark colour, poor mouthfeel and masking of flavour are all negative attributes that are often associated with high-fibre baked products. Sources of soluble dietary fibre, such as oat bran, have been the focus of numerous new products. However, the level of oat bran in commercial baked products is usually low, possibly because bran adversely affects product texture compared to the original formulations (Hudson, Chiu and Knuckles, 1992).

In view of this, processors are engaged in incorporating fibre into various baked products to satisfy consumer needs for increased fibre intake without sacrificing attributes (Fondroy, White and Prusa, 1989). One of the problems has been that healthy food choices are often viewed as being in conflict with enjoyable eating.

Like fibre, resistant starch (RS) has been shown to provide benefits such as increased digestive tract activity and the production of desirable metabolites like short-chain fatty acids (SCFA) in the colon (Yue et al., 1998). Compared to conventional fibres, it has many advantageous features. It is a natural white source of dietary fibre, has a bland flavour and gives a better appearance, texture and mouthfeel than other typical fibres.

The sensory attributes of a food interact with consumer physiological, behavioural and cognitive factors to exert influence on consumer perception (Di Monaco, Cavella, Torrieri and Masi, 2007). Sensory properties are important factors in the determination of consumer liking. However, when consumers buy food products their choice is also influenced by other information such as identity, origin, safety and nutritional properties. Product information has been shown to affect consumer choice. Recent studies reported in the literature have investigated the effects of health and nutrition information (Aaron, Mela and Evans, 1994; Daillant and Issanchou, 1993; Kähkönen and Tuorila, 1999; Mialon, Clark, Leppard and Cox, 2002; Sosa and Hough, 2006).

From earlier research, it is known that motivated consumers can translate an assumed health benefit into a better liking for a new product (Kähkönen, Tuorila and Rita, 1996). Even if the degree of liking remains unaltered, the purchase interest may increase if a health benefit is expected (Tuorila, Andersson, Martikainen and Salovaara, 1998). Many consumers today feel that sensory pleasure must be sacrificed in order to achieve the goal of a healthy diet (Tuorila and Cardello, 2002). Despite this, Gilbert (2000), Augustin (2001) and Cox, Koster and Russell (2004) have stressed that consumers are not so willing to compromise on the taste of functional foods for eventual health benefits. As suggested by Urala and Lähteenmäki (2004), a relevant issue is whether any consumers are willing to accept functional foods that taste worse than the equivalent conventional foods.

Although fibre information is used increasingly on a variety of food packaging, particularly for cereal foods, not many studies of the effect of fibre-related information on consumer perception have been reported in the literature (Mialon et al., 2002).

The aim of this study was to investigate to what extent the effect of fibre information could change responses to a muffin made with 15% of resistant starch, which is considered a functional fibre. The novel aspect of this work is that since this fibre does not impart any of the negative attributes that fibre-rich products usually possess (darker colour, coarser texture or dryer mouthfeel), consumers do not need to 'sacrifice' their expectations in order to eat what is, in principle, a healthier food.

2. MATERIALS AND METHODS

2.1. Consumers

One hundred and two consumers were recruited among the students and personnel of the Instituto de Agroquímica y Tecnología de Alimentos, Valencia, Spain, on the basis of their interest, availability and liking or being regular purchasers of bakery products. They were between 21 and 69 years of age; 32% were men and 68% were women.

2.2. Products

Three types of muffins were evaluated in the study. One was an experimental sample containing RS, the other two were plain muffins and wholemeal muffins obtained from a local supermarket. The experimental muffin was made following a traditional recipe but replacing part of the flour with RS: the formulation (expressed as a percentage of weight) consisted of wheat flour (11%) (Harinera Vilafranquina, S.A., Teruel, Spain; composition according to the miller: 14.5% moisture, 10.1% protein); resistant starch (15%) (HI-MAIZE 260, National Starch Food Innovation, Manchester, United Kingdom; composition data provided by the supplier: 12% moisture, 63.9% dietary fibre); sugar (26%) (Azucarera Ebro, Madrid, Spain); liquid pasteurized egg white (14%) and liquid pasteurized yolk (7%) (Ovocity, Llombay, Spain); full-fat milk (13%) (Puleva Food, Granada, Spain); refined sunflower oil (12%) (local supermarket); sodium bicarbonate (1.03%); citric acid (0.79%) and grated lemon peel (0.18%). The egg white was whipped in a mixer (Kenwood Major Classic, UK) for 2 min at speed 7 (maximum). Sugar was then added and mixed in for 30 s at speed 7. Egg yolk, citric acid and half of the milk were added and mixed in at speed 3 for 1 min. Wheat flour, RS, sodium bicarbonate and grated lemon peel were added and mixed in at speed 3 for 1 min. Oil and the rest of the milk were added and mixed in at speed 4 for 3 min. The batter was placed in an automatic dosing unit (positive displacement pumps, output shaft speed=109 r.p.m., output shaft torque=7.6 N.m.) (Edhard Corp., Hackettstown, USA), and each paper muffin cup (50-mm diameter) was filled with 40.5 g of batter. The muffins were baked in a conventional oven for 6 min at 225 ºC and for a further 6 min at 175 ºC. The oven and oven trays were always the same, the trays were placed at the same level in the oven and the number of muffins baked was always the same. The muffins were prepared the day before the sensory sessions. The two commercial muffin samples were chosen because their lists of ingredients bore the greatest similarity to the experimental muffin (Table 1).

Table 1. List of ingredients of the muffins evaluated

Ingredients	Plain muffin	Wholemeal muffin	RS experimental muffin
Wheat flour	X	X	X
Wholemeal flour	---	**X**	---
Resistant starch	---	---	**X**
Sugar	X	X	X
Milk	X	X	X
Egg	X	X	X
Oil	X	X	X
Leavening agent	X	X	X

2.3. Sensory evaluation sessions

The consumers tasted the three type of muffins and rated the 'appearance', 'texture', 'flavour', 'overall acceptance', and two health-related variables, “how healthy do you think it is?” and “how nutritious do you think it is?”, on nine-point category scales with the ends anchored with “dislike extremely” through to “like extremely” for the sensory attributes and “not at all healthy” through to “extremely healthy” and “very little” to “very highly” for the health-related variables (Mialon et el., 2002). They also evaluated “intention to consume” and “intention to purchase” on nine-point category scales with the ends anchored with “I would definitely consume/buy it” through to “I would definitely not consume/buy it” and a neutral central point: “maybe I would or maybe I would not consume/buy it”.

The experiment included two sensory sessions. In the first session the consumers evaluated the three samples blind. The three samples were presented in random order and were then rated. During the second session, one week later, the consumers were asked to evaluate the three samples again. This time the lists of ingredients of the three types of muffins (Table 1) were presented on a card. The fibre content was also indicated, as follows: plain muffin 6.3g per 100g, wholemeal muffin 9.83g per 100g and resistant starch muffin 9.4g per 100g. The consumers were asked to read the information card before answering any questions.

Immediately after the second session, the consumers also completed a questionnaire related to food and nutrition in order to obtain their consumer profiles. The questions on health consciousness (Schifferstein and Oude Ophuis, 1998; Mialon et al., 2002) were completed by the consumers. They were rated on a nine-point scale (from "I am not at all concerned" to "I am totally concerned"). This was done in order to identify subgroups or types of consumers whose acceptance may differ with the provision of information.

Data acquisition was performed using Compusense® *five* release 4.6

software (Compusense Inc., Guelph, Ont., Canada)

2.4. Data analysis of health consciousness

Health consciousness scores were calculated from the questionnaire results (Table 2).

Table 2. Health consciousness questionnaire

Scale/Item	**Mean**	**SD**
Health consciousness		
1. I have the impression that I sacrifice a lot for my health	5.72	2.45
2. I think a good knowledge of how to eat healthily is important	8.21	1.77
3. I continually ask myself whether something is good for me	5.80	2.46
4. I think my health is influenced by my food	7.60	1.65
5. My health depends on the foods I consume	7.46	1.46
6. I consider that the deterioration of my health is very important	7.87	1.69
7. I am prepared to sacrifice things for my health	7.06	1.84
8. My diet is well-balanced and healthy	6.73	1.82
9. I am concerned about the quantity of salt that I get in my food	5.14	2.54
10. I am concerned about the quantity of fat that I get in my food	7.10	1.86
11. I am concerned about the quantity of fibre that I get in my food	5.96	2.19
12. I am concerned about the risk of high blood pressure	5.80	2.46
13. The amount of sugar I get in my food is important	6.19	2.13
14. The amount of vitamins and minerals that I get in my food is important	7.21	1.71
15. I am concerned about the amount of cholesterol that I get in my food	6.62	2.30

The matrix formed by consumers as rows and each of the health consciousness questions as columns was analyzed by principal component analysis using the covariance option. The biplot for the first two principal components is shown in Figure 1.

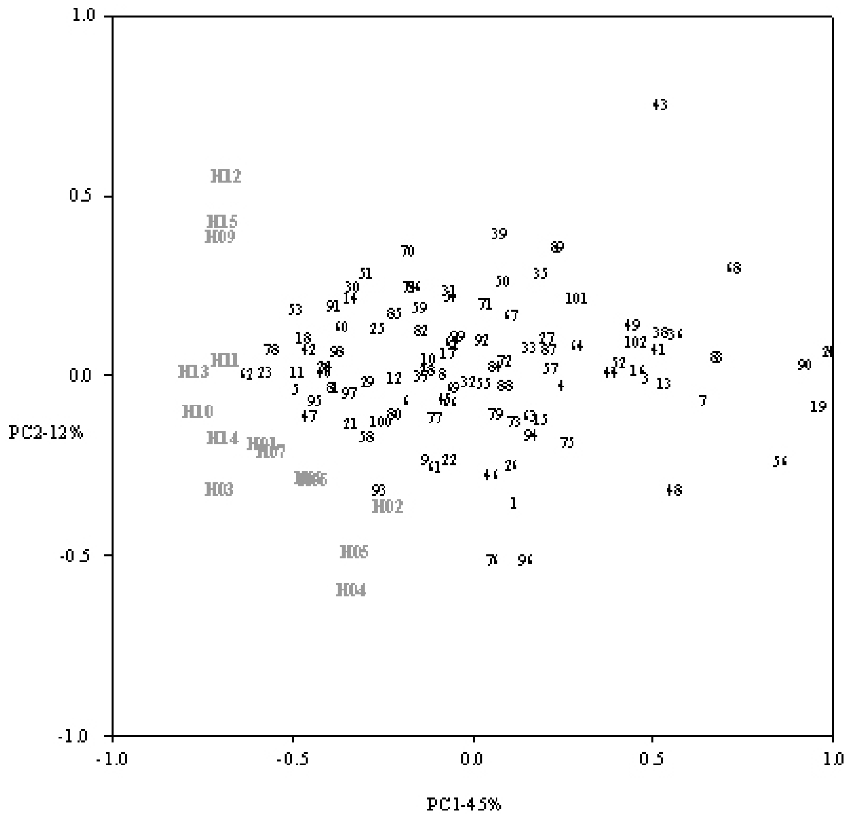


Figure 1. Principal component analysis of the matrix formed by consumers as rows and health consciousness questions as columns. H1 to H15 refer to health consciousness questions (see Table 2) and numbers refer to consumers.

All the questions are relatively close together, revealing that they are correlated. To obtain an overall health consciousness score for each consumer, the average score for the 15 questions was calculated. This average will be referred to as the average health consciousness (AHC). The higher the AHC, the higher the overall health consciousness of the consumer.

PCA analyses were performed using SPSS for Windows Version 12 (SPSS Inc., USA).

2.5. Data analysis of sensory scores

Residual Maximum Likelihood Technique (REML) is a computationally intensive ANOVA technique which is particularly well suited to analysing data that include fixed, random and covariate effects (Horgan and Hunter, 1993).

In the present study the fixed effects were sample (plain, wholemeal and resistant starch) and ingredient information (without and with), the random effects were consumer, testing day and sample presentation order and the covariate was AHC. Health consciousness was considered a covariate as it was non-design information that came with each consumer. As stated above, the consumers participated in two sessions, a week apart, one without information and the other with information. Not all the consumers did the test on the same days, so the testing day was included as a random effect.

Thus the model was:

- Fixed effects: sample*ingredient information*AHC
- Random effects: consumer/testing day/sample order.

To estimate the significance of the effects, the Wald test was used. Statistical analysis was performed using procedures in GenStat 9th edition (VSN International Ltd, Hemel, Hempstead, U.K.)

3. RESULTS AND DISCUSSION

The significant effects obtained from the REML analysis are summarized in Table 3.

3.1. Effect of information and sample on the sensory attributes

Information had no effect on the samples' 'appearance'. For 'appearance', plain muffins received the highest score (plain = 7.2) and there were no significant differences between wholemeal and RS (wholemeal = 5.7; RS = 6.0). For 'flavour', there were significant differences between the three samples, as the scores were plain muffin = 7.0, RS = 6.2 and wholemeal = 5.4.

Significant information × sample interaction was found for 'texture' and 'overall acceptance' ($p < 0.05$) (Table 3).

Table 3. Significant effects determined by Residual Maximum Likelihood analysis

		Appearance	Texture	Flavour	Overall acceptance	Healthy	Nutritious	Intention to consume	Intention to purchase
	df	*p*							
Information (Info)	1	0.193	**0.001**	**0.003**	**0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Health Consciousness (Health)	1	0.32	0.842	0.808	0.82	0.251	0.182	0.34	0.282
Sample	2	**<0.001**	**<0.001**	**<0.01**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Info×Health	1	**0.043**	**0.038**	**<0.001**	**<0.001**	0.156	0.539	**<0.001**	**<0.001**
Info×Sample	2	0.885	**0.005**	0.099	**0.05**	**0.026**	**<0.001**	0.066	**0.03**
Health×Sample	2	0.061	0.277	0.057	**0.045**	0.814	0.428	**0.005**	**0.021**
Info×Health×Sample	2	0.978	0.455	0.299	0.327	**0.011**	0.288	0.205	0.334

Figure 2 shows the interaction for 'overall acceptance'.

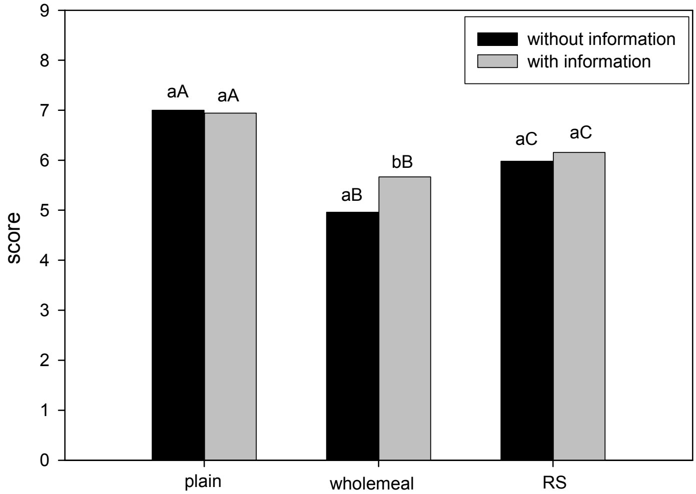


Figure 2. Effect of information on 'overall acceptance' ratings. [a,b] Significant differences between with and without information for each muffin *p*<0.05 [A,B,C] Significant differences between plain, wholemeal and fibre-enriched (RS) with information and plain, wholemeal and fibre-enriched (RS) without information. *p*<0.05

There were no significant differences in the ratings for plain and RS muffins but the score for the wholemeal muffin increased when the information was provided. When the information was not provided there were significant differences between all the samples, with plain muffin scoring the highest and wholemeal muffin the lowest; when the information was provided there were also significant differences between the three samples, although plain muffin still scored the highest (Figure 2). The results for 'texture' followed the same pattern. Kihlberg, Johansson, Langsrud and Risvik (2005) studied the changes in perceptions of bread, expressed through changes in liking, due to information provided, and found that increased liking for three of the four breads was a result of information on their cholesterol-reducing effect: when this information was provided to the consumers the liking for the lowest-scoring sample increased the most, unlike the level of the highest-scoring sample. Campbell and Bell (2001) found that consumers rated the acceptability of a low-fat sugar-free cake significantly lower than the regular cake, but when the consumers knew what they were eating, the acceptability of low-fat sugar-free cake increased significantly and no changes were found for regular cake.

The 'healthy' and 'nutritious' attributes presented the same behaviour. There were significant differences between the wholemeal and RS muffins when information was provided (Figure 3).

The RS received a lower score than the wholemeal muffin despite both presenting the same quantity of fibre, but the RS muffin presented the highest increase in score when the information was provided. These results are in agreement with Mialon et al. (2002), who found that fibre-enriched white bread and muffin scores displayed a greater increase when the information was provided than those for wholemeal bread and muffins. It is interesting that the 'overall acceptance' of the wholemeal muffin in the blind session was lower than for the fibre-enriched muffin but that in the 'nutritious' rating it scored higher than the fibre-enriched muffin. The consumers were able to distinguish between ‘wholemeal’ foods and ‘white’ foods. They know that one of the health benefits of eating wholemeal foods is primarily reported as being due to their fibre content. Wholemeal food can be identified by appearance, texture and other characteristics that consumers may find unattractive, which may be why the consumers rated the 'overall acceptance' of the wholemeal muffin lower despite being able to identify it as a wholemeal food.

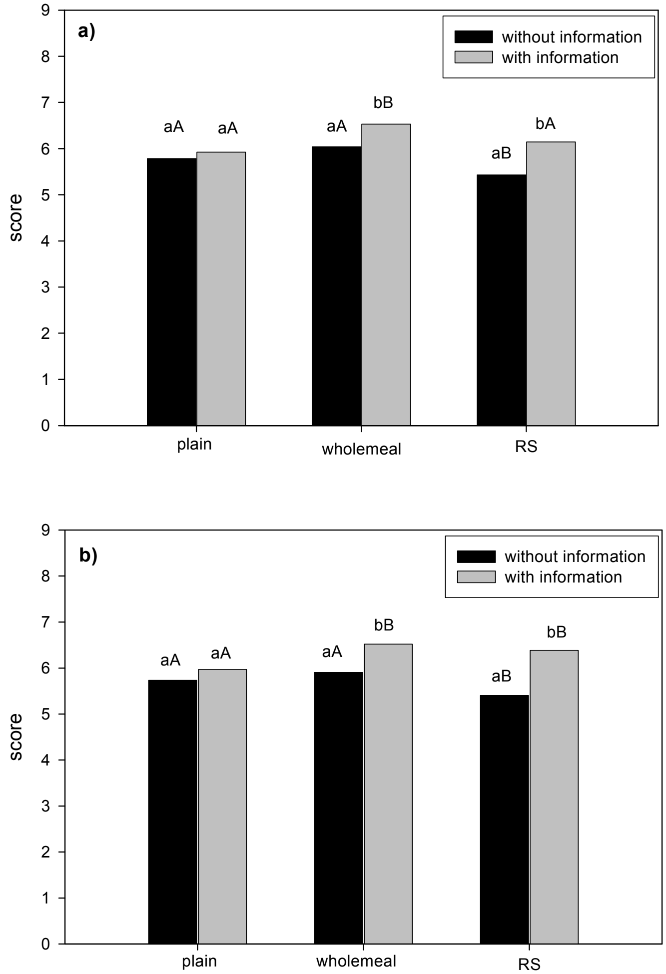


Figure 3. Effect of information on healthy (a) and nutritious (b) ratings. [a,b] Significant differences between with and without information for each muffin $p<0.05$. [A,B] Significant differences between plain, wholemeal and fibre-enriched (RS) with information and plain, wholemeal and fibre-enriched (RS) without information. $p<0.05$

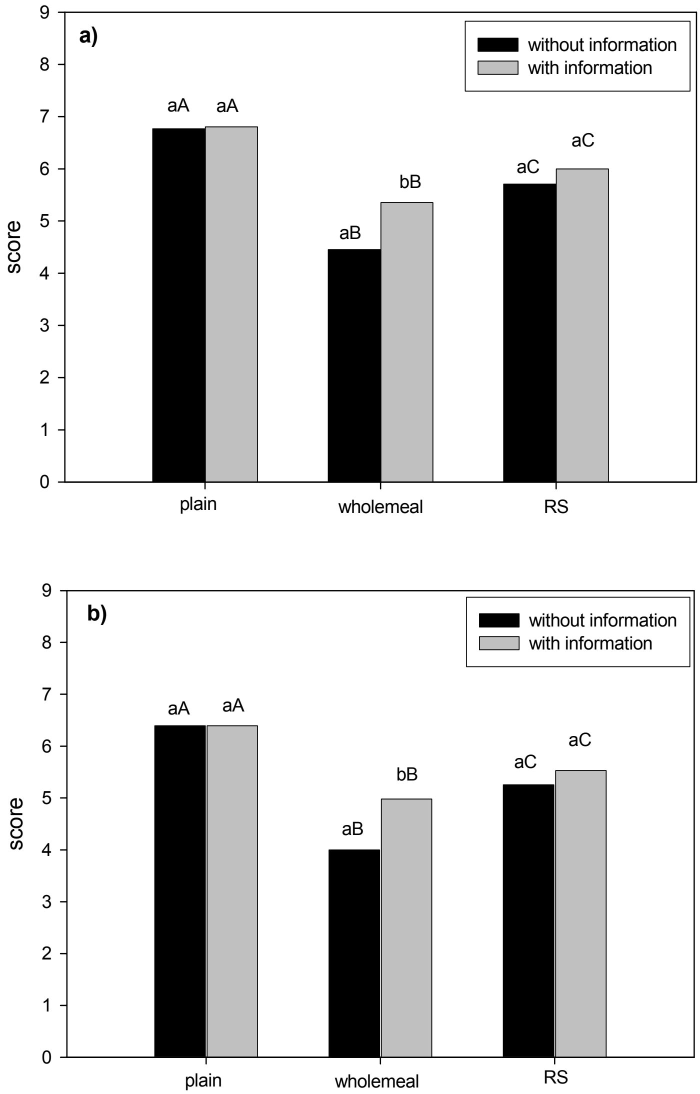


Figure 4. Effect of information on 'intention to consume' (a) and 'intention to purchase' (b) ratings. [a,b] Significant differences between with and without information for each muffin p<0.05. [A,B,C] Significant differences between plain, wholemeal and fibre-enriched (RS) with information and plain, wholemeal and fibre-enriched (RS) without information. *p*<0.05

As regards 'intention to consume' and 'intention to purchase', plain muffins scored the highest and wholemeal muffins the lowest, both with and without information (Figure 4), though there were significant differences between with and without information in wholemeal muffins.

The behaviour of consumers with regard to these two attributes was similar to that for 'overall acceptance'. Mialon et al. (2002) found that when information about the fibre content of English muffins was provided to consumers, the ratings for likelihood of consumption decreased slightly for the white muffin, increased slightly for the fibre-enriched muffin and stayed similar for the multigrain muffin.

The results confirm that the fibre information provided was well understood by the consumers and led to higher scores in the case of wholemeal muffins, but that the same information was not as well comprehended for fibre-enriched muffins.

3.2. Effect of health consciousness with respect to information on muffins.

The consumers' health consciousness had some influence when the information was provided.

The Information × Health Consciousness interaction (Info x Health) was significant for all the attributes except for 'healthy' and 'nutritious' (Table 3). Figure 5 shows the average for the 'overall acceptance' attributes of the three muffins in relation to Info × Health. When the information was provided, the 'overall acceptance' ratings were lower in the low health-consciousness group but the appearance ratings were higher in the high health-consciousness group.

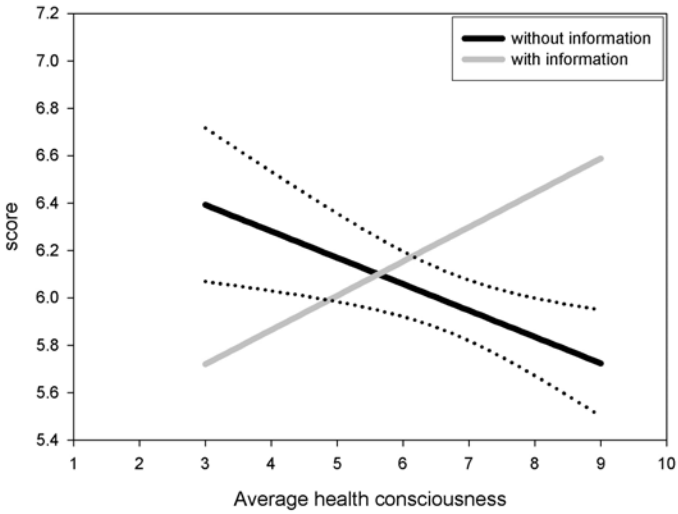
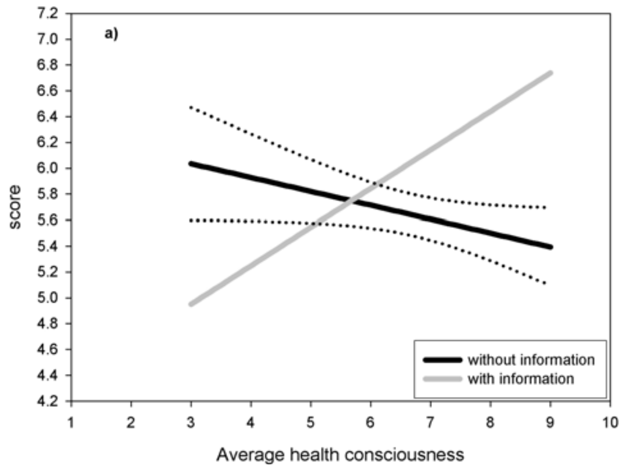


Figure 5. Effect of health consciousness on the average 'overall acceptance' ratings of the three muffins with and without information. (• • •) standard deviation (the deviations are similar for all the samples).

The other attributes also presented the same behaviour. The same pattern was observed for the 'appearance', 'texture' and 'flavour' attributes. As can be observed in Figure 6, the predicted consumer scores for 'intention to consume' and 'intention to purchase' behaved in the same way as the predicted scores for the sensory attributes, but were lower for the low health-consciousness group.

As can be seen in Figure 5, when the information was not provided the gradient of the line was negative but when the information was provided the gradient of the line was positive. When the information was not provided, the consumers became more demanding as their health-consciousness increased and scored the sample lower if they did not know what they were eating; when the information was provided and health-consciousness decreased, the consumers played down the importance of whether or not the sample contained fibre and the scores for all the samples were lower.



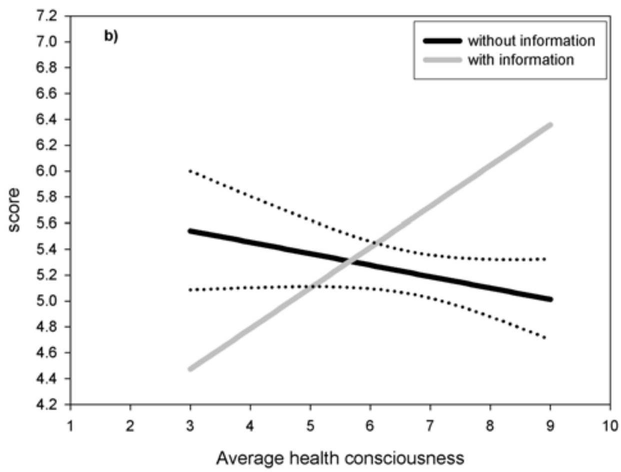


Figure 6. Effect of health consciousness on the average (a) 'intention to consume' and (b) 'intention to purchase' ratings for the three muffins with and without information. (• • •) standard deviation (the deviations are similar for all the samples).

The Sample × Health Consciousness interaction (Health x Sample) was significant for the sensory attribute of 'overall acceptance' (Table 3). Figure 7 shows that the predicted scores for plain muffins were the highest of the three samples and were practically the same for all the health-consciousness groups. The low health-consciousness group scored the wholemeal muffin lowest but the high health-consciousness group gave very similar scores to RS and wholemeal muffins. The predicted scores for RS muffins decreased as the health-consciousness of the consumers increased, whereas the consumer behaviour with regard to the wholemeal muffins was the contrary. This could be due to the highly health-conscious consumers' not knowing about RS and its properties and thus preferring not to have it in their everyday muffins.

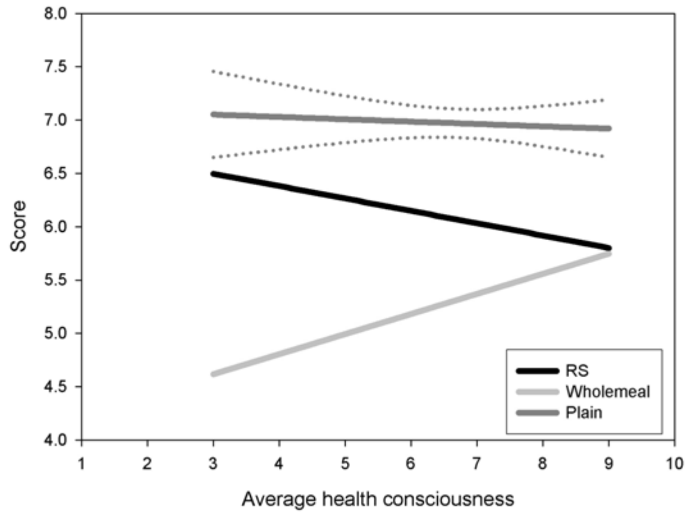


Figure 7. Effect of health consciousness on the 'overall acceptance' ratings of the muffins. (• • •) standard deviation (the deviations are similar for all the samples).

Health x Sample was also significant for 'intention to consume' and 'intention to purchase' (Table 3).

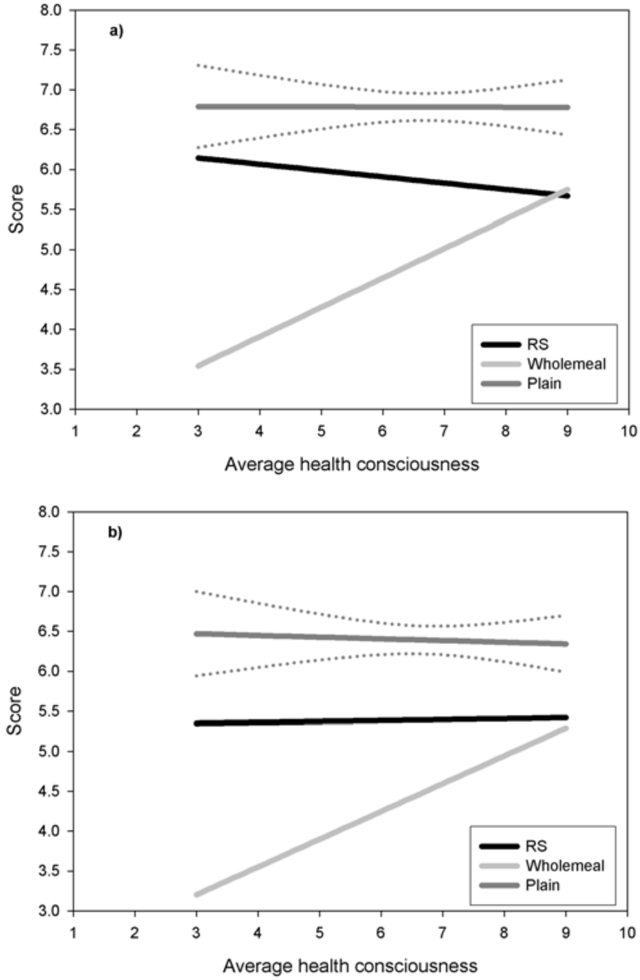


Figure 8. Effect of health consciousness on (a) 'intention to consume' and (b) 'intention to purchase' ratings of the muffins. (•••) standard deviation (the deviations are similar for all the samples).

Figure 8 shows the predicted score of the three samples for different health-consciousness related consumer behaviour patterns. The evolution of the predicted scores was similar to that in Figure 7, but the predicted scores for the RS muffins were practically the same for all the groups of consumers. In a study of the acceptability of muffins with flaxseed, consumers who did not think they needed to consume ‘health foods’ had an ‘indifferent’ and in some cases ‘negative’ attitude toward the flax muffins, which they considered a ‘health food’, and this may have influenced the rating that the flax muffins received (Ramcharitar, Bradie, Mattfeldt-Beman, Matsuo and Ridley, 2005). Tuorila et al. (1998) found a connection between how concerned consumers are about their fibre intake and their acceptance of snack foods labelled ‘high fibre’; however, in the present study that connection was not found for all the samples, as can be observed in Figure 7.

CONCLUSIONS

The knowledge of certain nutritional facts affects the way that consumers perceive the products. Wholemeal muffins received the lowest scores when no nutritional information was given to consumers but the scores increased when consumers knew the fibre content of the product: normally a higher level of fibre is always perceived as a 'healthier' product.

Paradoxically it seems that when the consumers read that a muffin is fibre-enriched but see a white muffin (because resistant starch provides quite a similar appearance to a plain muffin), they act as though they cannot quite believe it and score this muffin lower than the wholemeal muffin despite being informed that both have the same fibre content.

This study would indicate that when using alternative fibres that tend to retain the characteristics of the product with no added fibre, it could prove positive to give consumers more information on what these fibres are and how they work and thereby provide them with better criteria on which to base their choice.

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CONCLUSIONES

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- El presente trabajo demuestra la importancia que tiene en la elaboración de un producto de bollería (magdalena) el estudio tanto de las propiedades reológicas de la masa cruda como de las propiedades mecánicas o sensoriales del producto final horneado, frente a cambios en la formulación o en el proceso de preparación.

- El uso de una dosificadora automática produce rotura en los gránulos de almidón y disminuye el tamaño de los glóbulos de grasa dando lugar a una estructura más compacta. La viscosidad de la masa cruda en estas condiciones aumenta, revelando su importancia industrial. Sin embargo, los cambios descritos no afectan a las características del producto final horneado.

- La adición de almidón resistente (AR) modifica el comportamiento reológico de la masa cruda. Al aumentar la concentración de AR, la viscosidad aparente de la masa cruda disminuye: valores más bajos del índice de consistencia indican una estructura menos compleja. También se produce un descenso en la componente elástica de la respuesta dinámica atribuible a un efecto de dilución de las proteínas de la harina de trigo.

- La resistencia a la deformación del producto final horneado es el parámetro más sensible a la presencia de AR; su valor disminuye al aumentar la concentración de éste. Por otro lado, la elasticidad, cohesividad y resilencia no se ven afectadas a niveles de AR inferiores al 15%.

- Al aumentar la concentración de AR, la altura del producto horneado disminuye debido al descenso en la viscosidad de la masa cruda; el número de celdas de aire disminuye y su área aumenta. Todos los cambios descritos se traducen en una magdalena más compacta y con volumen menor.

- Durante el almacenamiento hasta 16 días, las magdalenas con un mayor contenido en AR permanecen más blandas.

- El estudio de la vida útil sensorial predice que después de 23 días de almacenamiento el porcentaje de rechazo para las muestras que contienen AR es menor que para las magdalenas control.

- Los resultados sensoriales obtenidos con un panel entrenado indicaron que en las magdalenas con AR se percibió mayor dulzor, mayor sensación de humedad y cierto grado de arenosidad. Estas características fueron detectables a partir de una concentración de AR del 10%.

- La aceptación determinada con un panel de consumidores indicó que las magdalenas con AR tienen una aceptación similar a las magdalenas control.

- El conocimiento de información nutricional (contenido en fibra) no aumentó la valoración de los consumidores. Probablemente debido a que los consumidores asocian la presencia de fibra a una serie de características negativas (color, textura, etc.) que no se encontraron en las magdalenas con AR.