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REVIEW

Formulation and Quality Attributes of Quinoa Food Products

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Abstract Diverse functional properties and gluten-free feature grant quinoa uniqueness among grain-related foods. This generates great scientific enthusiasms for quinoa-related product development worldwide. This review characterizes a wide variety of quinoa products launched during the last 5 years, including breads (sourdough and non-sourdough), Chinese-steamed bread, pasta, cookies, breakfast cereals, snacks, edible films and emulsion stabilizers. The focus is given to the impact of quinoa on diverse quality attributes of the products. Innovative approaches for counteracting the negative alterations in product properties caused by adding quinoa are discussed. Research directions on how to develop unique quinoa-based products are suggested.

Keywords Quinoa · Composite flour · Gluten-free · Texture · Property · Product development

Introduction

Pseudo-cereal quinoa (*Chenopodium quinoa* Willd.) has been cultivated for 50 centuries, dating back to the Aztec, Mayan and Incan civilizations. Nowadays, quinoa is among the most popular crops for the Quechua and Aymara people of rural South America (Graf et al. 2015). Quinoa can be cultivated in poor soils and high-altitude regions. Magnifying genetic variability has further broadened the adaptability of this crop to diverse agro-climatic habitats and edaphic conditions. This has increased the yields of diverse varieties in countries outside South America, such as the USA, Canada, India, Italy and China (Bhargava et al. 2007; Pulvento et al. 2010; Valencia et al. 2010; FAO 2011; Jacobsen 2011; Gonzalez et al. 2012). The world production of quinoa has kept growing over the last decade, and was over 100,000 tonnes in 2013 (FAOSTAT 2015) (Fig. 1).

Quinoa gains popularity among grain-related foods due to its various nutrients and bioactives. Quinoa proteins encompassing essential amino acids (lysine, threonine and methionine) are nutritionally well-balanced. The lipids containing unsaturated fatty acids (linoleic and linoleic acids) are considered healthy. Quinoa is also known by vitamins (folate and tocopherols), minerals (iron, copper, manganese, and potassium) and other phytochemicals (ecdysteroids, phenolic acids, and flavonoids such as kaempferol and quercetin) (Ng et al. 2007; Repo-Carrasco-Valencia et al. 2010; Vega-Gálvez et al. 2010; Alvarez-Jubete et al. 2011; Gómez-Caravaca et al. 2011; Kumpun et al. 2011; Miranda et al. 2011; Laus et al. 2012; Lutz et al. 2013; Nascimento et al. 2014). Furthermore, the celiac-toxic prolamin epitopes within quinoa protein, which were found absent in majority of quinoa varieties, could not activate any notable autoimmune response in celiac patients. Thus, quinoa could be used to create healthy gluten-free (GF) alternatives for people with gluten intolerance, wheat allergies, and celiac disease (CD) (Zevallos et al. 2012, 2014). The addition of quinoa grains has been approved to boost nutritional and functional features of cereal foods due to the above-mentioned factors (Vega-Gálvez et al. 2010; Hariadi et al. 2011; Valcárcel-Yamani and da Silva Lannes 2012; Mastromatteo et al. 2012).

Over the past 5 years, quinoa has been involved in the production of breads (sourdough and non-sourdough), Chinese

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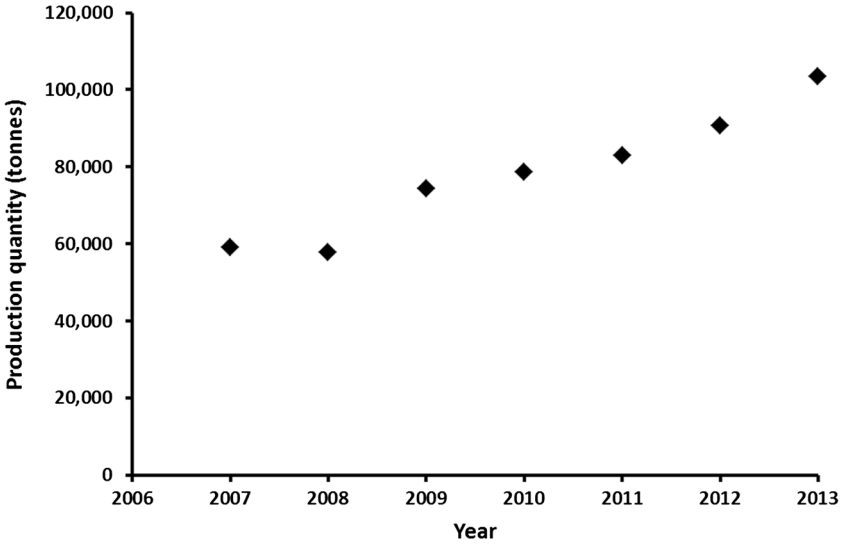

Fig. 1 World production quantity of quinoa from 2007 to 2013 (FAOSTAT 2015)

steamed bread, pasta (spaghetti and tagliatelle), snacks, cookies, edible films and food-grade Pickering emulsion (PE) (Table 1). Quinoa addition in the products appeared to alter the quality of the resulting products to various extents. For example, partial substitution of wheat flour (WF) with quinoa seeds (50 %) (Alvarez-Jubete et al. 2010) or quinoa flour (QF; 10 and 20 %) yielded breads with increased nutritional values and decreased specific volumes (Rodriguez-Sandoval et al. 2012). Incorporation of quinoa protein into chitosan film increased the tensile strength and water vapor permeability and decreased the water activity and thermal stability of the film (Araujo-Farro et al. 2010). Diverse approaches (formulation and process design), therefore, have been attempted to counteract the undesirable changes in the quality attributes of the resulting products with the quinoa additions. This mini-review presents the recent advances in the formulation and production of quinoa related food products. Variables influencing the quality attributes of different types of products are specifically addressed.

Chemical Components of Quinoa

A recent review has detailed the nutritional impacts of quinoa macro and minor components on the finished products but has much less emphasized their influences on the physicochemical attributes of the intermediate (such as thermo-mechanical properties of dough) and the finished products (such as textural characteristics of bread) (Repo-Carrasco et al. 2003; Valcárcel-Yamani and da Silva Lannes 2012). In fact, structural and physicochemical properties of quinoa components, beyond their basic nutritional values, greatly determine the process feasibilities and quality attributes of quinoa-containing products.

Starch

Starch is the most abundant macro component and a major energy source of quinoa foods. The content ranged from 48 to 69 % of the whole kernel, in keeping with their genetics, agronomic factors, and starch extraction methods (Vega-Gálvez et al. 2010; Steffolani et al. 2013). Starch typically consists of two types of molecules: amylose and amylopectin. Starches of various quinoa varieties differ in amylose content, granular structure and size and molecular structure of amylopectin and amylose. These differences probably result in the difference in physiochemical properties of starch during processing in presence of water. These properties include swelling, solubility, pasting, gelatinization, and retrogradation (Lindeboom et al. 2004; Pérez and Bertoft 2010). As a result, the quality attributes of quinoa foods vary as a result of these different physiochemical properties. Quinoa starch (QS) of diverse genotypes tends to have lower amylose contents (7–27 %) than most other starches (Lindeboom et al. 2005). QS granules are small (0.5–3 μm in diameter) with a narrow particle size distribution (Lindeboom et al. 2004). These granule features make octenyl succinic anhydride modified QS granule (Fig. 2.) a successful candidate to stabilize food-grade Pickering emulsions (Matos et al. 2013) and enable native QS to produce edible films with unique physiochemical properties (Araujo-Farro et al. 2010).

Protein

Protein content of quinoa seeds ranged from 14 to 18 %. Quinoa contains less glutamic acid and proline and more essential amino acids, such as methionine (4–10 g/kg dry matter (DM)) and lysine (51–64 g/kg, DM) (Gorinstein et al. 2002; Bhargava et al. 2007). Quinoa protein is composed mainly of globulins and albumins, with very little or no storage prolamin

Table 1 Formulation, characterization and quality parameters of representative quinoa-based food products

Products Reference	Nutritional and functional characteristics	Formulation and process variables	Physicochemical and sensorial evaluation methodology	Observations
Bread (non-sourdough)				
Rodriguez-Sandoval et al. (2012) (QF-WF bread)	QF: MC, 12.47 %; WAI, 2.31; WSI, 5.10 %; SP, 2.43	Formulations: flour, 500 g (QF 10, 20 %) yeast, 15 g; sugar, 15 g; NaCl solution (10 %, *w*/*w*), 100 mL shortening, 10 g. Bread making (6 steps): 1st kneading, 8.5 min; 1st proofing, 100 min (30 °C, 85 % RH); 2nd kneading, 2 min; 2nd proofing, 25 min; 3rd proofing, 60 min; baking, 210 °C (25 min)	Dough rheology (at mixing stage): water absorption, development time, development, stability, mechanical weakening. Dough rheology (at pasting stage): minimum torque, thermal weakening, peak torque, cooking stability, setback. Bread quality, weight, width, height, SV.	As compared with 100 % WF, adding 10 and 20 % QF: (a) Rheological parameters of dough at mixing stage: water absorption decrease by 2 and 0 %, respectively; development time increased by 7 and 14 %, respectively; stability increased 20 and 19 %, respectively; mechanical weakening decreased by 75 and 37.5 %, respectively. (b) Rheological parameters of flour at pasting stage: no changes in minimum torque; thermal weakening increased by 8 and 5 %, respectively; peak torque decreased by 2 and 8 %, respectively; cooking stability decreased by 11 and 9 %, respectively; setback decreased by 38 and 61 %, respectively. (c) Bread quality: weight decreased by 2 and 0 %, respectively; width increased by 3 and 0 %, respectively; height increased by 11 and 0 %, respectively; SV decreased by 11 and 30 %, respectively.
Chlopicka et al. (2012) (QF-WF bread)	QF: TPC, 2.8 mg/g dw; TFC, 92 μg/g dw. Antioxidant capacity: TEAC FRAP, 58.7 mg Trolox/100 g dw; TEAC DPPH, 6.22 mmol Trolox/kg dw	Formulation: QF, 15 and 30 %; sugar, 3.3 %; iodinated salt, 3.3 %; yeast, 1.7 %. Bread making (8 steps): 1st mixing, 15 min; 1st growing, 15 min; 2nd mixing, 10 min; 2nd growing, 15 min; 3rd growing, 45 min (35 °C); 3rd mixing, 10 min; 4th growing, 15 min (45 °C); baking, 50 min (180 °C)	TPC, TFC. Antioxidant capacity: TEAC FRAP, TEAC DPPH. Sensory evaluation. Panelist, 31 students, 19–24 years old, 20 women and 11 men: 10-point hedonic scale: 0, disliked; 4–8, moderately acceptable; 10, extremely liked. Organoleptic attributes: consistency, colour, odor. Taste descriptions: interesting tasty, natural, strange taste, vapid, not to eat, bad taste, little pronounced, gummy, crusty, sweet, salty, tart, milky difficult to determine, delicate.	As compared with 100 % WF bread, (a) Adding 15 % QF: TPC, TFC, TEAC FRAP and TEAC DPPH of bread increased by 11, 36, 11 and −47 %, respectively; colour and consistency rating (median values) of bread decreased by 3 points; odor of bread increased 0.5 point; more than 30 % testers reported an interesting, delicate and crusty taste of breads. (b) Adding 30 % QF: TPC, TFC, TEAC FRAP and TEAC DPPH of bread increased by 49, 41, 20 and −40 %, respectively; no significant differences in organoleptic attributes (consistency and odor), except for the colour decreased 1 points. (c) Only 15 % testers declared a bad taste of bread.
Hager et al. (2012) (QF bread)	QF: MC, 12.3 %. Ash, 2.4 %	Formulation: QF, 100 %; salt, 2 % BF; sugar, 2 % BF; yeast, 3 % BF; water addition, 95 %. Bread making (5 steps): 1st mixing, 1 min; 2nd mixing, 1.5 min. Fermentation, 15 min (30 °C, 85 % RH). Proof,	Dough characteristics: dough development, gaseous release. Loaf characteristics: MC, weight, bake loss, SV. Crumb characteristics: rate of staling, water activity, TPA. Slice structure analysis: slice area, number of cells, area of cells, cell elongation.	As compared with 100 % WF bread, adding 100 % QF, (a) Dough development and gaseous release: maximum dough development height decreased by 55 %; time for reaching maximum dough rise decreased by 69 %;

Table 1 (continued)

Products Reference	Nutritional and functional characteristics	Formulation and process variables	Physicochemical and sensorial evaluation methodology	Observations
		75 min (30 °C, 85 % RH). Baking, 45 min (190 °C)	Microstructures of dough and bread by SEM. Shelf life analysis: 12 days, RT, mould count. Sensory evaluation: panelists, 22 trained panelists 23–43 years old, 5 men and 17 women. Aroma analysis, 0–3 point scale: 0, not detectable; 1, weak intensity; 2, medium intensity; 3, high intensity. Aroma liking, 9-point scale: 1, dislike very much; 5, neither like nor dislike; 9, like very much.	total volume of gaseous release increased by 14 %. (b) Loaf characteristics: SV decreased by 42 %; bake loss increased by 37 %; MC increased by 18 %; hardness increased by 277 %; springiness decreased by 7 %; chewiness increased by 325 %; rate of staling decreased by 95 %; a_w increased by 0.7 %. (c) Crumb cell characteristics QF bread: slice area decreased by 41 %; number of cells decreased by 35 %; cell elongation decreased by 6 %; area of cells decreased by 1 %; thickness increased by 0.7 %. (d) Sensorial attributes of QF bread: overall aroma liking decreased 4 points; dominated pea-like (medium to high intensity) and cooked potato and mould (weak–medium intensity), unlike medium intense yeast-like note, and weak malty and buttery notes of WF bread crumb. (e) Microstructure of batters and breads: no noticeable structural differences between QF and WF breads.
Stikic et al. (2012) (Quinoa seeds-WF bread)		Formulation: WF, 80, 85, 90 and 100 %; quinoa seeds, 10, 15 and 20 %; yeast, 3 %; salt, 2 %	Composition analysis: proximate analysis (AOAC methods); mineral composition; amino acids analyses by reversed-phase HPLC); column, Waters Nova-Pak C18 4 μm, 3.9 × 150 mm). Rheological characteristics: dough water absorption, dough development, dough stability, dough degree of softening, SV. Sensory characteristics: appearance attributes (shape, crust colour, nuance, brightness, and uniformity); crust texture and aroma-odor; crumb texture and aroma-odor. 0–5 point scales: 0–2.5, unsatisfactory; 2.5–3.5, good; 3.5–4.5, very good; 4.5–5.0, excellent.	As compared with 100 % WF bread, (a) Adding 20 % quinoa seeds: protein, fat, crude fibre, K, Fe and Mg of the bread increased by 16, 10.3, 185, 17, 48, and 73 %, respectively; MC, ash and starch content of the bread decreased by 5, 13 and 4 %, respectively; lysine, methionine and histidine levels increased by 26.5, 8.8 and 9.8 %, respectively; water absorption of dough, degree of softening and bread SV decreased by 2, 5 and 5 %, respectively. (b) Sensory score: bread with 15 % quinoa seeds, 5.0; bread with 10 % quinoa seeds, 4.98; bread with 20 % quinoa seeds, 4.88. (c) All WF breads with quinoa seeds had pleasant aroma (flavour and taste) slightly bitter and fully acceptable; yellow-reddish crispy crust; middle of the bread: light colour, finely structured, uniform pores.
Alvarez-Jubete et al. (2010) (Quinoa seed-WF bread)	Quinoa seeds: TPC, 71.7 mg GAE/100 g dw. Antioxidant capacity: TEAC DPPH, 34.8 ($IC50_{Trolox}/IC50_{sample}$) × 10^5; TE DPPH, 57.7 mg TE/100 g dw; FRAP, 92.1 mg TE/100 g dw.	Formulation: quinoa seeds, 50 and 100 %; RF (only for 50 % QF bread); vegetable oil; bakers fat; xanthan gum; fresh yeast; salt; caster cane sugar. Bread making (4 steps): 1st mixing, 1 min; 2nd mixing, 2 min; proof,	Phytochemicals: TPC. Antioxidant capacities: TEAC, DPPH, TE DPPH and FRAP. HPLC analysis, phenolic acids, flavonoids.	As compared with 100 % WF bread, (a) Adding 50 % quinoa seeds: TPC, TEAC DPPH, TE DPPH and FRAP of the bread increased by 5, 24, 19 and 13 %, respectively; presence of 2 flavonoids (quercetin glycosides 7.1 μmol/100 g dw

Table 1 (continued)

Products Reference	Nutritional and functional characteristics	Formulation and process variables	Physicochemical and sensorial evaluation methodology	Observations
	Simple polyphenols; protocatechuic acid, 9.7 μmol/100 g dw; vanillic acid derivative, 4.9 μmol/100 g dw. Flavonoids; kaempferol glycosides, 36.7 μmol/100 g dw; quercetin glycosides, 43.4 μmol/100 g dw	35 °C, 45 min, 80 %; baking, 220–225 °C (20 min). Quinoa seeds sprouting: steeping, 24 h (15 °C); germinating, 82 h (10 °C); sample turn, every 30 min; bud from the germinated seeds, 0.5 cm; germinated seeds freeze-dried and frozen at −20 °C		and kaempferol glycosides 7.7 μmol/100 g dw); no detectable phenolic acids. (b) Addition of 100 % quinoa seeds: TPC, TEAC DPPH, TE DPPH and FRAP of resulting bread increased by 90, 24, 19 and 6 %, respectively; presence of 2 flavonoids (quercetin glycosides 17.1 μmol/100 g dw, and kaempferol glycosides 19.2 μmol/100 g dw). As compared with seeds without germination, seed spouting; TPC, TEAC DPPH, TE DPPH and FRAP increased by 105, 3, −13 and 70 %, respectively.
Calderelli et al. (2010) (Quinoa grain-WF bread)		Formulation: quinoa grains, 6 g; sugar, 3 g; salt, 0.7 g; benzoic acid, 0.2 g; strengthener, 0.5 g; WF, 47 g; wheat fibre, 4 g; soya oil, 4 g; yeast, 4 g; water, 27 g. Bread making, 170 °C (30 min)	Proximate analysis: MC, ash, protein, lipids, fibre, minerals. GC analysis: fatty acids composition. Colour and texture analysis: crust and crumb of the bread. Sensory analysis: 103 potential consumers (local bakery); 20 g bread slices; overall linking, 7-point hedonic scale.	As compared with WF bread with 6 % flaxseed: WF breads with 6 % quinoa grains had (a) Low levels of saturated fatty acids, low levels of *trans*-fatty acids (approximate 0.5 %). (b) Overall linking score of 5.8 (out of 7, well accepted by potential consumer), 85 % of those interviewed potential consumer affirming that they would buy the product due to the taste and health potentials. (c) Lighter (both crust and crumb) and yellow crumb; (d) Texture similar to flaxseed bread.
Mäkinen et al. (2013) (quinoa malt-RF-PF bread gluten free)		Quinoa germination: (1) steeped for 5 h, (2) germinated, 15 °C (24 h), (3) kilned, 45, 50, 55 and 65 °C; (4) removed cotyledons; (5) ground malts; (6) sieved (0.25 mm sieve). Formulation: RS, 50 %; PS, 50 %; yeast, 2 %; water, 90 % (on flour basis); whey protein isolate, 10 % vegetable oil, 6 %; salt, 2 %; xanthan gum, 0.3 %; HPMC, 0.3 %; quinoa malts :1, 2.5, 5 %. Bread making: mixing, 2 min; proof, 30 min (30 °C, 85 % RH); baking, 45 min (190 °C)	α- and β-amylase activities of malts. Batter attributes: pasting properties, rheology, and density. Bread attributes:density, crumb hardness, SEM, CLSM micrographs.	Germination of quinoa: decreased proteolytic activity by 28 %; no significant effect on no influence on α-amylase activity. Germination of oat: increased α-amylase activity α- and β-amylase activities by 15,900 % and by 360 %; no significant effect on proteolytic and lipolytic activities. Oat malt addition: decreased batter viscosities during proofing and heating; decrease bread density by 15 %; formed more open crumb; overdosing deteriorated the product due to high α-amylase activity. Quinoa malt addition: no significant effect on the baking properties due to low α-amylase activity; no impact on bread or batter densities.
Bread (sourdough)				
Vogelmann et al. (2009) (QF sourdough)		Fermentation I: QF, 100 %; baker's yeast, 1 %; starter mixture, 10 % (equal parts of the rye sourdough I, rye sourdough II, commercial rye full sour, rice starter,	Fermentation time, PH, TTA, microbial counting, micro-analysis by PCR-DGGE, bacteriological culture and rRNA gene sequence analysis.	The dominant specie identified: LAB: *L. fermentum, L. helveticus*, *L. paralimentarius*, *L. plantarum*,

Table 1 (continued)

Products Reference	Nutritional and functional characteristics	Formulation and process variables	Physicochemical and sensorial evaluation methodology	Observations
		sorghum starter, teff starter and cassava starter); fermentation, 30 °C until a stable microbiota form. Fermentation II: QF, 100 %, *lactobacilli* and yeasts isolated from the dominating microbiota of fermentation I. Final counts of 10^7 CFU/g dough; fermentation, 30 °C, 10 days		*L. pontis, L. spicher;* yeast: *Issatchenkia orientalis, Saccharomyces cerevisiae.* Quinoa sourdoughs in both formation I and fermentation II dominated by: *L. nparalimentarius* (LAB), *S. cerevisiae* and *I. orientalis* (yeasts). As compared with 100 % WF dough. Quinoa dough in fermentation I: fermentation time, 12 days; pH 3.8–3.9; TTA, 35.3–38.6 (°SH); cell counts, LAB, 3×10^9–2.7×10^9 CFU/g; yeasts, 1.1×10^6–4.6×10^6 CFU/g. Quinoa dough in fermentation II: fermentation time: 15 days; pH 3.7–3.8; TTA, 22.3–28.7 (°SH); cell counts, LAB, 1.3×10^9–3.0×10^9 g; yeast,/g; yeast, 8.4×10^6–1.8×10^7 CFU/g.
Wolter et al. (2014) (QF bread)	QF: MC, 12.3 %; protein, 13.8 %, fat, 8.6 %; α-amylase activity, 0.17 IU/g; protease activity, 22.0 IU/g	Sourdough starter:QF, 50 %; water, 50 %; sucrose, 5 %; initial cells: *Weissella cibaria* MG1 (10^8 CFU/g dough); fermentation, 30 °C (24 h). Non-sourdough-containing breads: QF, 100 %; salt, 2 %; sugar, 2 %; dry-yeast, 3 %; water, 95 % (BF). Sourdough bread: QF, 80 %. Sourdough, 20 %; salt, 2 %; sugar, 2 %; dry-yeast, 3 %; water, 95 % (BF). Bread making GF bread, 190 °C (45 min). WF bread, 220 °C top, 235 °C bottom; (30 min)	Fermentation analysis: cell counts, PH, TTA. Metabolites: EPS, PSO, GlcOS. Rheological analyses: deformation, elasticity. Dough rheology: bread characteristics. Sensory evaluation: 22 trained panelists. Aroma (0–3 point scale): 0, not detectable; 1, weak intensity; 2, medium intensity; 3, high intensity. The odorant reference: buttery, butane-2,3-dione (120 μg/L); cooked potato-like,3 methylthio-propanal (140 μg/L); fatty, (E,E)-deca-2,4-dienal (7.7 μg/L); grassy, hexanal (1000 μg/L); mouldy, geosmin (2.1 μg/L); pea-like :3- isobutyl-2-methoxypyrazine (3.9 g/L); popcorn-like; roasty, 2-acetyl-1-pyrroline (12 μg/L); oat flake-like, (E,E,Z)-nona-2,4,6-trienal (2.6 μg/L). Aroma liking (9-point scale): 1, dislike very much; 5, neither like nor dislike; 9, like very much.	In compared with WF bread, (a) Adding QF (sourdough): deceased AF by 93 %, increased elasticity14%, formed high amount of EPS during fermentation, formed low amount of GlcOS (a mixture of PSO and isomalto-oligosaccharides) during formation, decreased cell count by 9 %, increased PH by 11 %, increased TTA by 5 %. (b) Adding QF (sourdough): decreased bake loss by 32 %, increased MC by 15 %, increased a_w by 2 %, decreased SV by 58 %, increased hardness 605 %, increased staling rate by 200 %; crumb properties: decreased slice area by 51 %. decreased number of cells by 35 %, decrease cell volume by 5 %, decreased porosity by 6 %, decreased brightness by 28 %. (d) Adding QF (non-sourdough), decreased bake loss by 9 %, increased MC by 4 %, increased a_w by 1 %, decreased SV by 42 %, increased hardness 273 %, increased staling rate by 60 %; crumb properties: decreased slice area by 42 %, decreased number of cells by 46 %, increase cell volume by 19 %, decreased porosity by 1 %, decreased brightness by 35 %. Sensory characteristics of quinoa bread crumb: “pea” and “cooked potato-like” aroma (medium intensities), “grassy” and “mouldy” (weak-medium intensities), “haylike” (a weak intensity).

Table 1 (continued)

Products Reference	Nutritional and functional characteristics	Formulation and process variables	Physicochemical and sensorial evaluation methodology	Observations
Coda et al. (2010) (QF-BWF-AF-CF bread)	QF (d.m.): MC, 9.3 %; carbohydrates, 68.9 %; protein, 13 %; lipid, 5.8 %; fibre, 5.9 %; ash, 0.6 %	NCB formulation: WF, 117 g; BWF, 15 g; AF, 15 g; CF, 80 g; QF, 15 g; tap water, 150 mL; baker's yeast, 2 % (*w*/*w*). NCSB formulation: sourdough SC48:5, 8 %; WF, 117 g; tap water, 75 mL; baker's yeast, 2 % (*w*/*w*). SC48n sourdough: BWF, QF/CF/QF = 1:1:5.3:1. Starter, *L. plantarum* C48. Control dough (CT0 and CTi) erythromycin, 0.05 mg/g. No bacterial inoculums; pH 4.0; CTi, incubated (24 h, 30 °C); CT0, not incubated. Sourdoughs (S1): initial cells, 5×10^8 CFU/g; incubated, 24 h (30 °C)	GABA, Glu, FAA. TPA analysis: SV, hardness, springiness, cohesiveness, resilience, fracturability. Colour analysis: *L*, *a**, *b**. Image analysis: black pixel area (%), number of cells, mean area (mm^2), mean perimeter (mm)	As compared with 100 % wheat: (a) Quinoa control dough (CT_0): GABA increased by 1014 %, Glu increased by 426 %, FAA increased by 59 %. (b) Quinoa control dough (CTi): GABA increased by 388 %, Glu increased by 2591 %, FAA increased by 977 %. (c) Quinoa sourdoughs (S1) started with *L. plantarum* C48: GABA increased by 559 %, Glu increased by 1015 %, FAA increased by 982 %. (d) Quinoa sourdoughs (S1) started with: *L. lactis* subsp. *Lactis* PU1: GABA increased by 151 %; Glu increased by 1803 %; FAA increased by 868 %. As compared with WFB, for NCB and NCSB breads, TPA analysis revealed: SV decreased by 14 and 4 %, respectively, hardness increased 33 and 23 %, respectively, springiness decreased by 15 and 0 %, respectively, cohesiveness increased by 3 and 1 %, respectively, resilience decreased by 6 and 6 %, respectively, fracturability increased by 198 and 179 %, respectively. Colour analysis revealed: *L* decreased by 7 and 23 %, respectively, a^* increased by 31 and −12.3 %, respectively, b^* decreased by 8 and −7 %, respectively. Image analysis revealed: black pixel area decreased by 26 and 5 %, respectively, number of cells detected increased by 33 and 59 %, respectively, mean area decreased by 5 and 39 %, respectively, mean perimeter increased by 21 and 17 %, respectively.
Dallagnol et al. (2013) (QF-WF slurries)		QF preparation: seeds: washed (cold water); dried, 48 °C 24–48 h; final a_w, 0.30–0.35. Slurry formulation: QF, *L. plantarum* CRL 778. Fermentation: pH 6.0 (30 °C)	Microbial counts: pH. HPLC analysis: lactic acid, acetic acid, hydroxyphenyllactic acid, phenyllactic acid. Protein hydrolysis (SDS-PAGE), TFF (ninhydrin–cadmium method).	During slurry fermentations by *L. plantarum* CRL 778 growth and lactic acid production, in quinoa was 9.8 log CFU/mL and 23.1 g/L, respectively, in wheat was 8.9 log CFU/mL and 13.9 g/L, respectively. At 8 h of incubation, quinoa protein hydrolysis, 40–100 %; wheat protein hydrolysis, 0–20 %; quinoa slurries had 24 peptides and 5 g/L free amino acids, antifungal compounds (phenyllactic and hydroxyphenyllactic acids) synthesized from Phe and Tyr in quinoa by *L. plantarum* CRL 778, antifungal strain approx. 2.6-fold higher than those in WF

Table 1 (continued)

Products Reference	Nutritional and functional characteristics	Formulation and process variables	Physicochemical and sensorial evaluation methodology	Observations
Snack (gluten-free) and cookies				
Diaz et al. (2013) (QF-corn snack)	Dietary fibre, 11.5 %	4 formulation: 20 % kañiwa/80 % corn, 20 % quinoa/80 % corn, 20 % amaranth/80 % corn, 100 % corn. Extrusion: WC, 15, 17 (19 %); SSP, 200, 350 and 500 rpm; die T, 150, 160, and 170 °C	Chemical composition: lipid stability; hardness, hexanal formation, WC.	The chemical and physical property of the resulting extrudes listed from the highest to the lowest: dietary fibre, 20 % kañiwa/80 % corn > 20 % quinoa/80 % corn > 20 % amaranth/80 % corn > 100 % corn; hexanal formation, 20 % kañiwa/80 % corn > 20 % quinoa/80 % corn = 20 % amaranth/80 % corn = 100 % corn (11 and 76 % RH); hardness, 20 % amaranth/80 % corn > 100 % corn > 20 % quinoa/80 % corn > 20 % kañiwa/80 % corn; water content, 100 % corn 20 % amaranth/80 % corn > 20 % quinoa/80 % corn > 20 % kañiwa/80 % corn.
Onwulata et al. (2010) (QF-WPC-CP snack)	Quinoa grain: MC, 11 %; protein, 16 %; fat, 7 %; ash, 43 %; non-soluble fibre, 4 %	Formulation: QF, 100 %; WPC, 12.5 %; CP, 12.5 %. Extruder setting: T, 35–100 °C (9 zones); SSP, 600 rpm; drying, 60 °C (10 min); storage, 20 °C. Baking, 205 °C (24 min). Frying: deep fried, 190 °C (60 s); vegetable oil	MC; WAI. Samples (1.0 g) plus distilled water (1010 mL); held, 15 min shaking/5 min; centrifuged, 1000×*g* (15 min); supernatant dried 90 °C (overnight). Pasting analysis by RVA; flour (2.5 g) plus distilled water (25 g), 50 °C kept for 4 min, 50–95 °C at 12 °C/min, 95 °C kept for 15 min, 95–50 °C at 12 °C/min; paddle rotating at 160 rpm. Thermal properties by DSC, 25–30 mg raw blend mixtures and milled extruded specimen, 20–200 °C. Scan rate, 1 °C/min in vitro rate of the digestion; RAG (20 min digestion); SAG (120 min digestion); CSLM. Components in the powder particles. For baked and fried specimens, density, porosity, breaking strength. Breaking strength (hardness); texture analyzer, breaking strength: the maximum force required for breaking the extruded samples (30 mm pieces).	As compared with quinoa extruded snack, (a) Adding WPC, the resulting quinoa snack: WSI increased by 12.5 %, WAI decreased by 10 %, peak viscosity decreased by 39 %, breakdown viscosity decreased by 30 %, peak temp gelatinization decreased by 2 %, percent gelatinized from raw decreased by 0.7 %, glycemic potential (20 min) decreased by 1 %, glycemic potential (120 min) increased by 11 %; (b) Adding WPC and CP, the resulting quinoa extruded snack: WSI increased by 50 %, WAI decreased by 16 %, peak viscosity decreased by 41 %, breakdown viscosity decreased by 54 %, peak temp gelatinization decreased by 2 %, glycemic potential (20 min) decreased by 18 %, glycemic potential (120 min) decreased by 91 %. (c) Photographic images of quinoa baked products: snack without WPC and CP: puffed in the middle, pillow-like; snack with WPC: shrinkage and uneven puffing; snack with WPC and CP: shrinkage, uneven puffing, intense discolouration. As compared with quinoa-baked snack, adding WPC without or with CP, the resulting snack: MC deceased by 12 % and 45 %, respectively, bulk density decreased by 3 % and increased by 3 %, respectively, particle density no changes, apparent porosity, volume expansion increased by 2 % and deceased by 39 %, respectively, area deceased by 43 % and 21 %, respectively.

Table 1 (continued)

Products Reference	Nutritional and functional characteristics	Formulation and process variables	Physicochemical and sensorial evaluation methodology	Observations
				As compared with quinoa-fried snack, adding WPC without or with CP, quinoa baked snack, MC decreased by 25 and 29 %, respectively, bulk density increased 35 % and decreased by 10 %, respectively, particle density had no changes, apparent porosity, volume expansion decreased by 57 and 47 %, respectively, area decreased by 51 and 66 %, respectively.
Harra et al. (2011) (QF/peanut butter, chocolate chip cookie)			Texture attributes: penetration force, withdrawal force, shear force. Sensory tests: chewiness/tenderness, saltiness, sweetness, preference, 30 panelists, 9-point scale, triangle tests.	100 % QF cookies were significantly sweeter and chewier than 100 % WF cookies. QF substitution at 50 and 100 % was an acceptable replacement for all-purpose WF in peanut-butter, chocolate-chip thumbprint cookie.
Pasta (spaghetti or tagliatelle)				
Chillo et al. (2009b) (QF tagliatell)		Formulation: CMC, 0.1, 0.2 and 0.3 %; WPI, 0.1,0.2 and 0.3 %; PS, 5, 10 and 15 %; casein, 0.1, 0.2 and 0.3 %; chitosan, 0.1, 0.2 and 0.3 %; QF, 69.7, 69.8 and 69.9 %; pre-gelatinized QS, 5, 10 and 15 %; tagliatelle making: kneading, 15 min. QS pre-gelatinization: QF water mixture; heating, 80 °C; cooling, to 40 °C	Dynamic-mechanical properties: G', G'', tan δ (G''/G'). Test setting: temperature, 25 °C; frequency, 0.05–10 Hz; reference, 3 Hz. Oscillatory frequency. Static-mechanical properties: elastic modulus in tension (EC). Tenacity stress-strain tests: temperature, RT; preload force, 10^{-3} N; force ramp, 0.1 N/min.	As compared with the semolina, quinoa dough had decreased G' by 6.3 %, deceased G'' by 97.6 %, deceased tan δ by 35.1 %; quinoa dough with pre-gelatinized starch: no difference in rheological properties as compared with those of the semolina dough.
Mastromatteo et al. (2012) (QF spaghetti)		Formulation: flours, QF, 15, 20, 30, 60 and 70 %; chick-pea flour, 5 and 10 %; broad bean flour, 10 %; maize flour, 10, 50 and 65 %; soy flour, 5 %. Pre-gelatinized QS, 10, 15 and 30 %. Drying: combinations of 3 stages: stage I (3 settings), 50 °C (30 min), 70 °C (60 min) and 50 °C (60 min); stage II (2 settings), 80 °C (400 min) and 80 °C (3000 min); stage III (2 settings), 50 °C (30 min) and 70 °C (40 min)	Dough rheology, elongation and shear viscosity. Sensory evaluation: a trained panel; 10 tasters; 9-point hedonic rating: 1, extremely unpleasant; 9, extremely pleasant; 5, satisfactory. Sensory attributes tested: for dry spaghetti, optimal cooking time, colour, resistance to break, overall acceptability. For cooked spaghetti, bulkiness, adhesiveness, taste, overall acceptability.	Adding pre-gelatinized QS, increased elongation and shear viscosity of QF dough. Adding pre-gelatinized OS, increased the bulkiness and adhesiveness of QF spaghetti. Adding legume flours, increased elongation and shear viscosity of QF dough, increased the firmness of QF dough, sensory attributes of dry and cooked QF spaghetti was not improved.
Chillo et al. (2010) (QF-pre-gelatinized QS spaghetti)		QF, 53.3 %. QS, 20 %. Spaghetti extrusion: temperature, 35, 39, 43 and 46 °C; screw speed, 50 rpm; kneading, 10 min; extrusion number, 1, 2, 3 and 4; drying (3 stages): stage I, 50 °C (30 min); stage II, 85 °C (400 min); stage III, 50 °C (30 min). Starch pre-gelatinization, QS mixed with water; heating, 80 °C; cooling, 40 °C	Dough characteristics: gelatinization degree rheological properties: dry spaghetti, mechanical and sensorial characteristics. Sensory analysis, a trained panel of 10 tasters; 9-point hedonic scale; 1, extremely unpleasant; 9, extremely pleasant; OCT. Uncooked pasta: colour, homogeneity and overall acceptability. Cooked pasta at optimum cooking time: stickiness, bulkiness, firmness, aroma, taste overall acceptability.	Re-extrusion (repeated extrusion) number affected the extensional and shears viscosity quinoa dough, increased the dough gelatinization degree of the quinoa, decreased shear viscosity of quinoa dough, improved colour and homogeneity of quinoa spaghetti, no effects on the sensorial characteristics of quinoa cooked spaghetti.

Table 1 (continued)

Products Reference	Nutritional and functional characteristics	Formulation and process variables	Physicochemical and sensorial evaluation methodology	Observations
Chillo et al. (2009a) (QF-pre-gelatinized QS spaghetti)		Formulation (*w*/*w* dough basis): QF, 68.5, 68.4, 67.7, 64.5 and 66.5 %. Pre-gelatinized QS, 10, 20 and 30 %. Pre-gelatinized OS, 10, 20 and 30 %. CMC, 0.1, 0.2 and 0.3 %. Spaghetti making: kneading, 20 min; drying temperature, 75 °C; drying time, 6.6 h. Starch pre-gelatinization, QS mixed with water. Heat treatment at 80 °C; cooling to 40 °C	Dough rheological measurement: elongational viscosity and shear viscosity at 3 shear rates (10, 105.36 and 1111.13 s^{-1}). Spaghetti rheology: elongational and shear viscosity, stress at break. Sensory analysis: 10 trained tasters (panelists); 9-point hedonic scale: 1, extremely unpleasant; 9, extremely pleasant; 5, satisfactory (acceptability threshold). Sensorial attribute of uncooked pasta: colour, homogeneity. Sensorial attributes of cooked pasta: stickiness, bulkiness, firmness, flavour, taste and OCT.	Quinoa dough rheology: shear-thinning behaviour: a significant decrease in the elongational and shear viscosity at low shear rate, but not at at high shear rate when adding CMC, no effects when adding pre-gelatinized QS. Quinoa spaghetti mechanical properties: adding CMC and pre-gelatinized starch had no affect at a great extent the stress at break. Sensorial attribute of quinoa spaghetti, adding CMC and pre-gelatinized QS had no statistically effect on sensorial characteristics of dry spaghetti and OCT.
Lamacchia et al. (2010) (QF pasta dough)	QF: WC, 13.50 %; protein, 11.6 %; ash, 2.17 %; total fibre, 9.86 %	Formulation: QF, 70 %; water, 30 %; kneading time, 15 min	Rheological analysis: G', G'', tan δ. Stress-strain tests. Mechanical properties. Total UPP. SE-HPLC analysis: molecular size distribution and molecular weight distribution of dough polymeric proteins.	Polymeric proteins profile of 100 % quinoa dough showed 4 main peaks: peak 1, MW (3800–2500 kDa); peak 2, MW (630 and 398 kDa); peak 3, MW (50–39 kDa); peak 4, MW (15–19 kDa). SE-HPLC profile, quinoa dough: 3 main peaks; intermediate and small size proteins in large peaks; 10.1 % UPP; 19 % LPP.
Schoenlechner et al. (2010) (QF-AF pasta (gluten-free)		Optimized formulation: AF/QF/BWF = 20:20:60; egg white powder, 6 % (BF); emulsifier DMG, 1.2 % (BF); dough moisture, 30 %. Kneading, 15 min; extrusion (laboratory scale noodle press); drying, 42 °C (9 h); stored, 4 °C	Cooking time, weight and loss. Pasta firmness. Dough firmness. Colour	Among 3 GF ingredients, compact of dough matrix of listed form the highest to lowest: BWF > QF > AF; QF pasta had the highest cooking loss. Adding egg white powder (up to 6 % of flour), emulsifier DMG (1.2 % of flour) at moisture (30 %), the resulting pasta agglutinated better, texture firmness increased, cooking loss decreased, cooking stability increased, colour differ from wheat pasta, firmness of dough decreased, pasta surface became smoother.
Breakfast cereals				
Joye et al. (2011) (WF-rice flour-QF breakfast cereals)	QF: GA, 727 ppm; GABA, 89 ppm	Extrusion: QF, 3.6 %; screw speed, 250 rpm; extrusion temperature, 100 °C; MC, 26 %	Flake quality attributes: microbiological stability, crunchiness, flavour, odour, GABA, GA.	Adding QF, GA and GABA levels of ingredient mixture before extrusion (75 min incubation), after extrusion and flaking significantly increased by (192 and 122 %), (54 and 67 %) and (100 and 89 %), respectively; GA levels of resulting flake after roasting 3 min at 190 °C, 5 min at 160 °C and 2 min at 190 °C increased by 31, 62 and 149 %, respectively; no significant difference in GABA levels between roasted flakes with/without QF.

Table 1 (continued)

Products Reference	Nutritional and functional characteristics	Formulation and process variables	Physicochemical and sensorial evaluation methodology	Observations
Edible films				
Valenzuela et al. (2013) (QP/CH/OS film)	QF: g/100 g, dw. MC, 10.7 %; protein, 14.4 %; fat, 8.4 %; ash, 2.5 %; carbohydrate, 66.1 %	CH deacetylation degree, 75–80 %. FFS: Q-8 or Q-12 mixed with CH (2 g/100 mL) at different Q/CH ratios (0.1, 0.2 and 0.4); pH, 3.0; SO, 2.9, 3.8, 4.9 g/100 mL; T_{80}, 0.6, 0.8, 1.0 g/100 mL. FFC: mixing, RT, 10 min, 10,000 rpm. Sonication, 30 min. Casting: RT. DC, Q/CH film (50 °C, 7 h); CH film, 35 °C, 9 h. Condition, 23 °C, 60 % RH, 48 h. QP extraction suspended 18 g quinoa flour in 100 mL water adjusted the suspension to PH to 8 and 12 with 1 mol/L NaOH stirred each suspension at RT, 60 min; centrifuged each suspension at 21,000×*g*, 15 °C, 30 min	Mechanical property: TS, EAB. Barrier property: WVP, OP. Thickness, MC, a_w (at 25 °C). Structural analysis: X-ray diffraction, FTIR, SEM.	With Q-8 in CH film: Thickness increased by 59 %; TS decreased by 80 %; EAB increase 21 %; OP increased by 24,000 %; WVP decreased 31 %; MC decreased by 2 %. With SO in Q-8/CH film: Thickness increased by147%; TS decreased by 80 %; EAB increase 9 %; WVP increased by 30 %; OP increased by 521 %; MC decreased by 27 %.
Abugoch et al. (2011) (QP/CH film)	Laboratory QF extraction from defatted QF	FFS: QP (6.7 %, *w*/*v*)/CH (2 %, *w*/*v*) ratios, 4/1, 1/1, 1/4, 0/1 (*v*/*v*), respectively. PH, 3.0; FFC: mixing, 1 h; casting, 50 °C; condition, 22 °C (60 % RH, 3 days)	Mechanical properties: EAB, TS. Barrier property: WVP. Thickness, a_w (at 25 °C). Structure analysis: X-ray diffraction, FTIR, SEM. Thermal analysis.	Compared with pure CH films, the resulting film containing 20 % QP (without plasticizers): smooth, continuous and compact structure; increased EAB by 271 %; increased WVP by 147 %; increased thickness by 163 %; increased TS by 5 %; increased yellowish; decreased aw by 40 %; decreased decomposition temperature by 56 %.
Araujo-Farro, et al. (2010) (QS film)	QS (dw): total protein, 0.9 %; ether extractable lipids, 0.01 %; total fibre, 0.23 %; total ash, 0.21 %; amylase, 17.1 %	Formulation: QS, 4.0 g/100 mL; glycerol, 21.2 g/100 g QS; pH 10.7. FFC: DC, 36 °C (14 h); condition, 25 °C (58 % RH). QS extraction: (1) wash 1 kg grains 4 times to remove saponins; (2) steep 1 kg seeds (3 °C, 8 h); (3) mill the softened seeds; (4) screen and wash slurry through sieves (80, 200, 270 mesh); (5) repeat step 4 (5 times); (6) centrifuge (600×*g*, 4 °C, 20 min); (7) remove top of the sediments (containing protein and fibre); (8) suspend the starch cake; (9) repeat steps 6–8 (5 times); (10) suspend the starch in 0.20 % NaOH (pH 10.5) and stir (15 °C, 5 min); (11) centrifuge and re-suspend residues (neutralized with 1 M HCl); (12) freeze-dry the purified; (13) sieve the ground QS through 270 mesh and stored at 3 °C in sealed containers	Proximate analysis. Mechanical properties: TS, EAB, YM. Puncture test, force at break, EAB, barrier properties, WVP, OP, film thickness. Solubility. Optical properties: CIE *L**, *a**, *b**, opacity.	100 % QS film from the optimized formulation: self-supporting and peelable; colourless and transparent; flexible and easily handled; homogenous and smooth surface; thickness, 0.080 mm; water content: 11.25 %; WSI, 15.9 % (25 °C); TS, 7.56 MPa; EAB, 58.14 %; YM, 4.59 MPa/%; force at break, 7.05 N; EAB (puncture test), 0.95 %; WVP, 0.204 g/(mm^2 h kPa).

Table 1 (continued)

Products Reference	Nutritional and functional characteristics	Formulation and process variables	Physicochemical and sensorial evaluation methodology	Observations
Pickering emulsion stabilizer				
Matos et al. (2013) (modified QS)		Starch extraction, wet-milling process. QS modification: OSA with 1.8 % QS	Emulsion property: initial encapsulation efficiency; starch encapsulation stability	Emulsion composition: 8.25 % (*v*/*v*) internal water phase (W1) of NaCl and carmine dye; 33 % (*v*/*v*) phase (O) 1.8 % OSA-modified quinoa starch (214 mg/mL Miglyol 812 oil); 58.75 % external water phase (W2) with phosphate buffer and NaCl. Emulsion characteristics: Initial encapsulation efficiency ≥98.5 %); encapsulation stability (≥90 %) after 21 days storage at RT. Potential applications; formulation of reduced-fat food products; vehicles for encapsulation and delivery of nutrients during food digestion

Notes: a_w water activity, *ABTS* 2,2′-azinobis (3-ethylobenzothiazoline-6-sulphonate, *AC* antioxidant capacity, *AF* amaranth flour, *AS* amaranth starch, *AOAC* Association of Official Analytical Chemists, *BWF* buckwheat flour, *BF* based on flour weight, *CF* chickpea flour, *CIE L*, a*, b** colour space (brightness (*L**); redness (+*a**); greenness (−*a**); yellowness (+*b**); blueness (−*b**)), *CH* chitosan, *CLSM* confocal laser scanning microscopy, *CMC* carboxymethyl cellulose, *CP* cashew pulp, *DC* drying condition, *d.m* dry mater *DPE* double Pickering emulsions, *DPPH* 1,1-diphenyl-2-picrylhydrazyl, *d.w.* dry weight, *DIW* deionized water, *EAB* elongation at break, *EE* encapsulation efficiency, *EPS* exopolysaccharide, *ES* encapsulation stability, *FFA* free amino acids, *FFC* film-forming conditions, *FFS* film-forming solution, *FRAP* ferric-reducing ability of plasma, *FTIR* Fourier transform infrared spectroscopy, *GAE* gallic acid equivalent, *G′* storage modulus, *G″* loss modulus, *GA* glutamic acid, *GABA* gamma-aminobutyric acid, *GF* gluten-free, *GlcOS* glucooligosaccharides, *Glu* L-glutamate, *HPMC* hydroxypropyl methylcellulose, *HPLC* high-performance liquid chromatography, $IC50_{sample}$ the sample concentration that caused a decrease in the initial DPPH concentration by 50 %, *L lactobacilli*, *LAB* lactic acid bacteria, *L plantarum CRL 778* Lactobacillus plantarum *CRL 778 L plantarum C48 Lactobacillus plantarum* C48, *Lc lactis subsp. Lactis PU1 Lactococcus lactis* subsp. *Lactis* PU1, *LPP* large polymeric proteins, *O* oil phase, *OCT* optimal cooking time, *OP* oxygen permeability, *OSA* octenyl succinic anhydride, *MC* moisture content, *MS* maize starch, *NCB* non-conventional flour bread, *NCSB* non-conventional flour sourdough bread, *OF* oat flour, *OP* oxygen permeability, *OS* oat starch, *PCR-DGGE* polymerase chain reaction and denaturing gradient gel electrophoresis, *PF* potato flour, *Phe* phenylalanine, *PSO* oligosaccharides panose-series, *PS* potato starch, *QF* quinoa flour, *QF-8* quinoa flour supernatant obtained at pH 8, *QP* quinoa protein, *QS* quinoa starch, *RAG* rapidly available glucose, *RF* rice flour, *RH* relative humidity, *RP* reversed-phase, *RT* room temperature, *RVA* rapid visco-analyzer, *SAG* slowly available glucose, *SE-HPLC* size-exclusion high-performance liquid chromatography, *SEM* scanning electron microscopy, *SDS-PAGE* sodium dodecyl sulfate polyacrylamide gel electrophoresis, *SF* soy flour, °*SH* Soxhlet Henkel degrees, *SO* sunflower oil, *SP* swelling power, *SSP* screw speed, *SP* swelling power, *SV* specific volume, *tan δ G″/G′*, *T* temperature, *TEAC* total antioxidant capacities, *TE* trolox equivalents, *TFC* total flavonoid content, *TPA* texture profile analysis, *TPC* total phenolic content, *TFAA* total free amino acids, *TS* tensile strength, *TTA* total titratable acidity, *Tyr* tyrosine, *UPP* unextractable polymeric protein, *WAI* water absorption index, *WF* wheat flour, *WPC* whey protein concentrate, *WPI* whey protein isolate, *WSI* water soluble index, *WVP* water vapor permeability, W_1 internal water phase, W_2 external water phase, $W_1/O/W_2$ water-in-oil-in-water w/w: % weight per weight *YM* Young's modulus

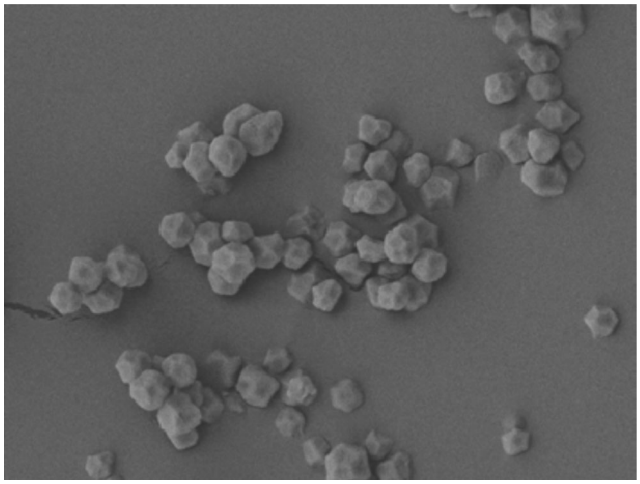

Fig. 2 Scanning electron micrograph (×5000) of octenyl succinic anhydride-modified quinoa starch granules (Timgren et al. 2011)

proteins which are the toxic proteins associated with celiac diseases (CD) (Drzewiecki et al. 2003; Gorinstein et al. 2002). CD is an immune-mediated disorder due to unfavorable responses to the ingestion of prolamins which are storage proteins from wheat (gluten), barley (hordein), rye (secalines) and oat (avenine). Because of characteristics of quinoa proteins, the use of quinoa in formulating GF products could be an advantage (Mäkinen et al. 2013). Abugoch et al. (2011) successfully incorporated QP into chitosan films and thus extended the uses of both quinoa and chitosan (Fig. 3). However, due to exceptional viscoelastic properties of gluten protein in WF, QF-containing WF dough has much lower gas retention during proofing and baking (Wolter et al. 2014).

Lipids

Lipid contents of quinoa seeds ranged from 4.4 to 8.8 %, which are higher than most other cereals. Stikic et al. (2012) found that adding 20 % QF increased the fat contents of resulting bread by 16 %. According to Calderelli et al. (2010), 55–63 % of the fatty acids (FA) in quinoa grains is unsaturated, with palmitic acid (PA; C16:0), oleic acid (OA; C18:1 *n*-9) and linoleic acid (LA; C18:2 *n*-6) being dominant. Adding 6 % quinoa grains to WF bread resulted in a lower amount of saturated FA, as compared with those in WF bread containing 6 % flaxseeds (Calderelli et al. 2010).

Minor Components

Minor components, such as vitamins and phytochemicals, contribute to the nutritional and functional properties of quinoa foods. Miranda et al. (2011) reported that variance in vitamin composition existed among the Chilean quinoa ecotypes, with the contents of vitamins E, B, B1 and B3 being 2.445–4.644 mg/100 g, 0.349–0.648 mg/100 g, 0.056–0.081 mg/100 g and 0.562–1.569 mg/100 g, respectively. α-tocopherol (TOH) and γ-TOH are the most naturally occurring forms for vitamin E in seeds, and they have been claimed to inhibit oxidation of quinoa food products (Ng et al. 2007). Polyphenols are ubiquitous in quinoa seeds and are most responsible for the antimicrobial and antioxidant potentials of quinoa (Hirose et al. 2010; Miranda et al. 2011, 2014). According to Gómez-Caravaca et al. (2011), free and bound phenolics of two Peruvian varieties were 2.746–3.803 and 0.139–0.164 g/kg, respectively. The dominant polyphenols in Peruvian seeds

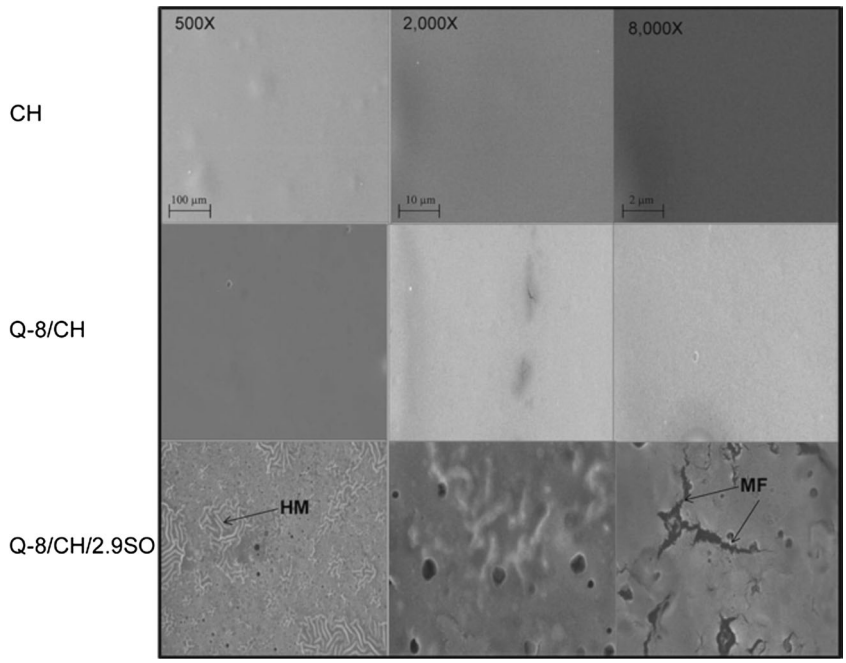

Fig. 3 SEM micrographs of the surface of chitosan film (*CH*), quinoa protein extract at pH 8/chitosan blend film (*Q-8/CH*) and quinoa protein extract at pH 8/chitosan/sunflower oil (2.9 g/100 mL) blend film (*Q-8/CH/2.9SO*). *HM* hydrophobic mass, *MF* micro-fractures (Valenzuela et al. 2013)

included 1-*O*-galloyl-*β*-D-glucoside, acacetin, protocatechuic acid 4-*O*-glucoside, penstebioside, ethyl-*m*-digallate, (epi)-gallocatechin and canthoside (Gómez-Caravaca et al. 2011). These anti-microbial polyphenols probably prolonged the mould-free shelf life of bread (Fig.4) and Chinese steamed bread (Wang et al. 2015).

Quinoa-Related Products

Focusing on reports from the recent 5 years, quinoa product development has been mainly on bread (sourdough and non-sourdough), Chinese steamed bread, pasta (spaghetti and tagliatelle), snacks, cookies, edible films and PE. Table 1 describes their formulation and quality attributes. Factors influencing the quality of each product are mainly discussed in this section.

Bread

Quinoa seeds or QF was typically blended into WF or other flours at diverse weight ratios (e.g. 6/94, 10/90, 12/88, 15/75, 20/80 and 50/50) to formulate composite flour for the bread making (Alvarez-Jubete et al. 2010; Calderelli et al 2010; Coda et al. 2010; Chlopicka et al. 2012; Rodriguez-Sandoval et al. 2012; Hager et al. 2012; Wolter et al. 2014). A majority of the studies expected the quinoa bread would share some characteristics of reference bread (typically 100 % WF breads) (Alvarez-Jubete et al. 2010; Rodriguez-Sandoval et al. 2012; Hager et al. 2012; Wolter et al. 2014). In fact, adding quinoa modified quality characteristics of the intermediate products (i.e. rheological properties of dough), as well as the finished products (i.e. texture of bread). The optimal water addition level in quinoa-based formulation was commonly determined using Farinograph (Alvarez-Jubete et al. 2010; Hager et al. 2012; Wolter et al. 2014). Hager et al. (2012) also applied empirical trial and error testing to determine the optimal water addition level for WF-GF composite flours. The empirical trial and error testing was based on resulting crumb structure and specific volume of loaf (Hager et al. 2012). Quinoa sourdough fermentation has been recently employed for their impacts on the sensory properties, texture, nutritional values and shelf life of the products.

Impact of Quinoa on Dough Properties

Adding QF altered thermo-mechanical properties of WF dough, such as cooking stability and thermal weakening (Rodriguez-Sandoval et al. 2012; Hager et al. 2012). As compared with 100 % WF dough, addition of 10 % QF decreased the cooking stability and setback of dough by 11 and 38 %, respectively, while increasing the thermal weakening by 8 %, as measured by Mixolab (Rodriguez-Sandoval et al. 2012). Stikic et al. (2012) found that adding 20 % quinoa seeds decreased water absorption and degree of softening of WF dough by 2 and 5 %, respectively, as measured by Farinograph. It is well known that dilution of a cohesive gluten matrix due to QF addition leads to lower elasticity and extensibility of dough. Hager et al. (2012) characterized the dough rise by the height and time for reaching a maximum value. The time and height for reaching 100 % QF dough rise were found to be 48 and 45 % of those for 100 % WF dough, respectively. Interestingly, the volume of gaseous release of 100 % QF dough was higher than that of 100 % WF dough (by 14 %), indicating a favorable sugar composition of the QF for yeast fermentation (Hager et al. 2012).

Impact of Quinoa on Nutritional Properties of Bread

Fortifying bread with quinoa is believed to be a practical approach to enhance protein quality. Adding 20 % quinoa seeds increased the protein content of bread by 16 %. The contents of lysine, methionine and histidine of this bread, in particular, were 26.5, 8.8 and 9.8 %, respectively, higher than those of 100 % WF bread (Stikic et al. 2012).

QF addition also increased the total phenolic content (TPC), total flavonoid content (TFC) and antioxidant capacity (AC) of bread (Alvarez-Jubete et al. 2010; Chlopicka et al. 2012). 2,2-Diphenyl-1-picrylhydrazyl (DPPH) and ferric ion-reducing antioxidant power (FRAP) assays were commonly used to evaluate AC of breads. Alvarez-Jubete et al. (2010) found that adding 50 % QF addition increased TPC, TFC and AC of DPPH and FRAP values of the bread by 5, 24, 19 and 13 %, respectively. Chlopicka et al. (2012) found that adding 15 % QF increased TPC, TFC and value of FRAP of bread by 11, 36 and 11 %, respectively, and decreased the DPPH value

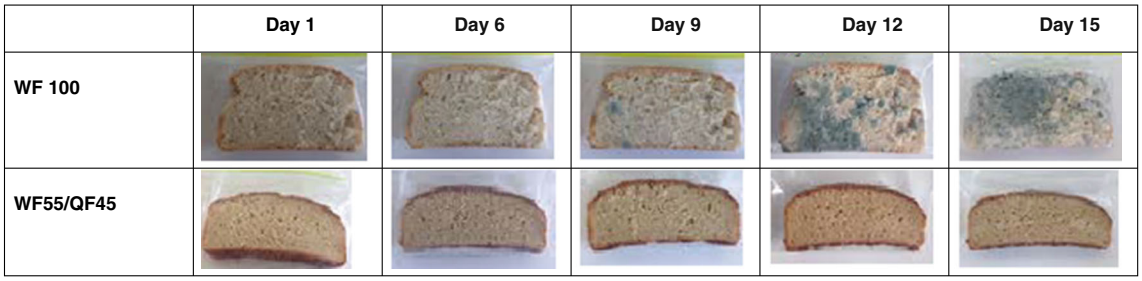

Fig. 4 Visual appearance of bread slices (20 mm thickness) stored at room temperature for 1, 6, 9, 12 and 15 days. *WF100* 100 % wheat flour, *WF55/QF45* 55 % wheat flour and 45 % quinoa flour (Wang et al. 2015; unpublished results)

by 47 %. This was likely due to compositional difference in phytochemical antioxidants of the samples, which responded somewhat differently in each type of evaluation assays. Huang et al. (2005) proposed that single electron transfer (SET) and hydrogen atom transfer (HAT) are relevant mechanisms for dietary antioxidants used in the human body. DDPH and FRAP assays are of the former (SET) mechanism. Other assays to reflect the HAT mechanism, such as oxygen radical absorbance capacity, are yet to be employed.

Impact of Quinoa on the Textural, Storage, and Sensory Quality of Bread

Specific Volume Loaf-specific volume (SV) refers to the ratio of volume to weight. SV is one of most studied quality attributes of bread. Adding quinoa flour or seeds decreased the SV of bread. Rodriguez-Sandoval et al. (2012) found that 10 % and 20 % QF addition decreased the SV of bread by 11 % and 30 %, respectively. Stikic et al. (2012) reported that adding 20 % quinoa seeds decreased the SV of bread by 5 %. Focusing on GF bread formulation, Hager et al. (2012) observed that SV of 100 % QF bread was smaller than those of 100 % WF bread by 42 %. Quinoa addition diluted wheat gluten matrix and resulted in the decrease of SV.

Textural Properties and Crumb Structures In addition to SV, textural properties (hardness, adhesiveness, gumminess and chewiness) of quinoa-containing bread were typically measured using instrumental texture profile analysis. Bread of 100 % QF had higher hardness (by 277 %) and chewiness (by 325 %) than bread of 100 % WF (Hager et al. 2012). The hardness of 100 % QF bread was 273 % higher than that of 100 % WF breads as confirmed by Wolter et al. (2014). Hager et al. (2012) applied cell imaging system to determine the size and distribution of the gas cells of bread slices. The slice structure was characterized by total slice area, number of cells (number of discrete cells per slice), area of cells (the total area of cells as a percentage of the total slice area), cell elongation (the degree of overall elongation of the cell structure in a particular direction) and wall thickness (the average thickness of cell walls) (Hager et al. 2012); 100 % QF replacing WF decreased total slice area, number of cells, area of cells and cell elongation of bread by 41, 35, 1 and 6 %, respectively, except for thickness which was increased by ~1 %. The increase in bread hardness and decrease in cell size are mostly due to the lack of gluten-type protein in quinoa.

Shelf Life The shelf life of bread was determined by the staling behaviour and microbial deterioration. Focusing on bread staling, Hager et al. (2012) replaced WF with 100 % QF and thereby decreased the rate of bread staling by 95 % (Hager et al. 2012). Wolter et al. (2014) found that replacing WF with 100 % QF decreased the staling rate of non-sourdough bread by 400 %. The reduced staling rate in quinoa bread was likely due to the starch component which had a lower retrogradation than wheat starch (Lindeboom et al. 2005; Hager et al. 2012). Focusing on microbial spoilage, Hager et al. (2012) found the first mould growth in breads from 100 % WF and 100 % QF (packed in a plastic bag) appeared on days 4 and 3, respectively. Wang et al. (2015) also found that adding QF to WF bread prolonged the mould-free shelf lives of both bread and Chinese steamed bread. The visual appearances of the representative slices of breads of 100 % WF and QF (45 %) and WF (55 %) mixture stored at room temperature under aerobic conditions are depicted in Fig 4 (Wang et al. 2015). The prolonged microbiological shelf life of bread could be due to the lower water activity of QF-containing bread than that of WF bread (Rodriguez-Sandoval et al. 2012), and the presence of antimicrobial phytochemicals such as phenolics in quinoa grains (Miranda et al. 2014).

Sensory Properties Sensory acceptance can be the most critical factor to ensure the successful application of quinoa in bread formulation. Over 30 % of trained panelists (n = 31) reported a delicate and crusty taste of bread containing 15 % QF. 85 % of panelists did not declare a bad taste on bread contain 30 % QF (Chlopicka et al. 2012). Another sensory study showed that breads containing 10, 15, and 20 % quinoa seeds had pleasant aroma (flavour and taste) with slight bitterness. However, panelists fully accepted the appearance attributes (i.e., shape, crust colour, nuance, brightness, and uniformity), texture, aroma and odour of crust and crumb of bread containing 10, 15 and 20 % quinoa seeds (Stikic et al. 2012). Therefore, it should be noted that, while affecting the dough rheology as well as the crumb structure and texture of bread, quinoa flour/seed partially replacing wheat flour may not negatively affect the consumer acceptance.

Aroma profile of QF-containing bread was analyzed by panelists in comparison to odorant references in several studies (Hager et al. 2012; Wolter et al. 2014). These odorant references included butane-2,3-dione (120 μg/L, buttery), 3-(methylthio)propanal (140 μg/L, cooked potato-like), 3-methylbutanal (120 μg/L, malty), geosmin (2.1 μg/L, mouldy), (E,E,Z)-nona-2,4,6-trienal (2.6 μg/L, oat flake-like), 3-isobutyl-2-methoxypyrazine, (3.9 μg/L, pea-like), 2-acetyl-1-pyrroline (12 μg/L, popcorn-like), acetic acid (18,000, 000 μg/L, vinegar-like) and butanoic acid (120,000 μg/L, vomit-like and cheesy) (Hager et al. 2012; Wolter et al. 2014). By using the chemical reference listed above, the aroma of bread of 100 % QF was described as with notes of pea-like (medium to high intensity) and cooked potato and mould (weak to medium intensity). These notes were distinguished from yeast-like (medium intense), malty and buttery (weak intensity) notes of wheat bread crumb (Hager et al. 2012). Wolter et al. (2014) reported that quinoa bread crumb was pea and cooked potato-like (medium intensities), grassy and

mouldy (weak to medium intensities), as well as hay-like (weak intensity).

Sourdough Bread

Sourdough bread is made from fermented dough with naturally occurring lactic acid bacteria (LAB) and yeasts present (Coda et al. 2010). Acidification, proteolysis, activation of some enzymes and synthesis of microbial metabolites cause several changes during sourdough fermentation. The use of sourdough offers the resulting bread an enhanced flavour, prolonged preservation and improved dough structure (Poutanen et al. 2009). Use of quinoa in sourdough could be an advantage as globulins and albumins in quinoa are more hydrophilic and are easily accessible by proteolysis enzymes, as compared with wheat gluten (Dallagnol et al. 2013). Like the non-sourdough bread, the textural properties of sourdough bread were affected by QF substitution. Wolter et al. (2014) found that completely replacing WF by QF decreased SV of bread by 58 %, and the hardness of 100 % QF sourdough bread were found to be 605 % higher than that of 100 % WF sourdough bread (Wolter et al. 2014). Again, the reduced SV and increased hardness of sourdough bread with quinoa could be attributed to the dilution of gluten matrix. Interestingly, replacing WF with 100 % QF had little effect on the staling of sourdough bread (Wolter et al. 2014). It should be noted that the increased hardness and reduced SV by quinoa addition may not be negative in the quality. For example, the popular rye sourdough bread had much lower volume and higher hardness than wheat bread.

In quinoa sourdough, dominant LAB species were *Lactobacillus paralimentarius* and *Issatchenkia orientalis* and yeast was *Saccharomyces cerevisiae* (Vogelmann et al. 2009). Other strains were also used. Employing *Lactobacillus plantarum (L. plantarum)* CRL 78 in formulation of quinoa sourdough improved the nutritional quality and shelf life of the products, because of its proteolysis and antifungal activity (Dallagnol et al. 2013). However, sourdough containing 20 % QF fermented with exopolysaccharide (EPS) producing *Weissella cibaria* MG1 did not improve physicochemical and organoleptic qualities of the resulting products (Wolter et al. 2014). In a study of Coda et al. (2010), a flour mixture of quinoa, amaranth, chickpea and buckwheat (at the ratio of 1:1:5.3:1) was fermented with baker's yeast (non-conventional flour bread (NCB)) and *L. plantarum* C48 sourdough (non-conventional flour sourdough bread (NCSB)), respectively. Compared with NCB, NCSB had the higher concentration of free amino acids, γ-aminobutyric acid (GABA) and phenolic compounds and antioxidant activity and lower rate of in vitro starch hydrolysis. Texture and sensory analysis also revealed good palatability and overall taste appreciation for NCSB (Coda et al. 2010). Commercially, there appears to be a lack of quinoa-containing sourdough bread.

Chinese Steamed Bread

Chinese steamed bread (CSB) is a traditional staple food widely consumed in Asia. The fermented dough is steamed, instead of baking (Zhu 2014). The feasibility of incorporating QF up to 75 % of flour in CSB was studied (Wang et al. 2015). It was difficult to form any consistent dough when the level of QF addition was over 80 % (Wang et al. 2015). Addition of QF decreased the SV, water activity and increased the hardness of CSB. Adding QF also resulted in a prolonged mould-free shelf-life of CSB. 30 % QF addition increased the shelf life by 1 day. The decreased SV and increased hardness could be due to the dilution effect on gluten. The increased microbiological shelf-life could be due to the decreased microbial activity and the presence of some anti-microbial phytochemicals in QF (Miranda et al. 2014; Wang et al. 2015). The nutritional properties and consumer acceptance of these resulting CSB need further sensory evaluation.

Pasta

Developing ingredients and additives to improve the quality of pasta made from quinoa has been attempted. Composite flour of WF and QF as well as QF (QF for gluten free products) was feasible for pasta (tagliatlle and spaghetti) formulation (Chills et al. 2009a, 2009b, 2010; Schoenlechner et al. 2010; Mastromatteo et al. 2012). Tagliatelle is long and flat pasta originally from Emilia-Romagna and Marche regions of Italy. The quality attributes of pasta dough can be characterized by water absorption capacity, cohesiveness, viscosity and elasticity of dough. The ideal pasta products should be strong, flexible, and smooth in surface (Fuad and Prabhasankar 2010). However, partially and completely substituting wheat semolina with QF altered certain quality parameters of dough and pasta due to gluten dilution. Adding QF decreased the strength and elasticity of dough, decreased tensile strength of dry pasta, increased cooking loss and decreased firmness of cooked pasta (Sissons et al. 2007; Cubadda et al. 2007). One approach to counteract these negative impacts was to use structuring agents. The reported agents included sodium carboxymethyl cellulose (CMC; 0.1, 0.2 and 0.3 %), whey protein isolates (WPI; 0.1, 0.2 and 0.3 %), casein (CAS; 0.1, 0.2 and 0.3 %), chitosan (CH; 0.1, 0.2 and 0.3 %), pre-gelatinized starches (PS) of quinoa, oat and legume (5, 10 and 15 %) and emulsifiers (Chillo et al. 2009a, b; Schoenlechner et al. 2010). The storage modulus (G') and loss modulus (G'') of the quinoa dough with pre-gelatinized starch addition were similar to those of the extruded tagliatelle dough made from semolina (Chillo et al. 2009a, b). Schoenlechner et al. (2010) found that adding egg white powder (up to 6 % of flour) and distilled monoglycerides (DMG) emulsifier (1.2 % of flour) decreased cooking loss and increased firmness, cooking stability and surface smoothness of the gluten-free

pasta from buckwheat-quinoa-amaranth flour mixture. Mastromatteo et al. (2012) reported that adding pre-gelatinized QS or legume flour increased elongation and shear viscosity of dough containing QF, while adding pre-gelatinized oat starch increased the bulkiness and adhesiveness of the pasta. Based on sensory evaluation, addition of CMC (0.1, 0.2 and 0.3 %) and pre-gelatinized starch (10, 20 and 30 %) did not affect the stress at break of dough and the sensory attributes of dry and cooked quinoa-based spaghetti (Chillo et al. 2009a, b).

Snacks and Cookies

Promising compatibility of QF with diverse food ingredients in snack production has been observed. Sour cassava starch snacks containing 5, 10, 15 and 20 % QF (Taverna et al. 2012), corn snacks containing 20 % QF (Diaz et al. 2013) and peanut butter cookies containing 50 and 100 % QF (Harra et al. 2011) were formulated. Taverna et al. (2012) introduced an optimal formulation (5 % QF) and extrusion conditions (screw speed, 250 rpm; temperature, 100 °C; moisture content, 15 %) for snacks production. In a comparison study by Diaz et al. (2013), the hardness of corn snacks containing 20 % QF was lower than that of snacks of 100 % corn. This may be due to the presence of other components, reducing the interactions among starch and proteins (Diaz et al. 2013). Harra et al. (2011) observed that replacing WF by 50 and 100 % QF granted sweeter and chewier features to the resulting peanut butter cookies. However, the reason is not clear.

Non-conventional Applications

Quinoa starch and protein were incorporated into edible film-forming solution to form a new material with enhanced mechanical properties. Quinoa starch was found also technologically feasible to stabilize food-grade Pickering emulsions (Table 1). The sensory properties of these non-conventional products are still unclear. Nevertheless, the biodegradable/edible nature of quinoa-related dietary biopolymers endows them with great potentials of applications in food systems (Araujo-Farro et al. 2010; Abugoch et al. 2011).

Quinoa Starch-Based Film

Araujo-Farro et al. (2010) used the quinoa starch (QS) for edible film production. The optimized conditions were defined as 100 mL solutions (pH 10.7) containing 24 g QS and 1.2 % glycerol as plasticizer. The conditions for film formation were at 36 °C for 14 h after casting. The resulting film under optimal condition presented the lowest water solubility, water vapor permeability, and oxygen permeability, and best mechanical properties (Araujo-Farro et al. 2010). In addition, Araujo-Farro et al. (2010) emphasized that other factors (such as film forming conditions) can be critical in the physicochemical properties of the films. The importance of the composition and structure of QS on the film formation was not well illustrated. The applications of QS films in food products remain to be explored.

Quinoa Protein-Based Film

Compared with single biopolymer, co-existing biopolymers possibly provide unique physicochemical properties of the films, thus extending their applicability and feasibility (Rhim and Ng 2007). Quinoa protein (QP) extract was blended with chitosan (CH) to formulate edible films (Fig. 3) (Abugoch et al. 2011). The resulting QP-CH films had increased thickness, tensile strength and elongation at break, and water-vapor permeability, and decreased water activity and thermal stability, as compared with CH films. These unique properties of QP-CH films were probably due to the cationic nature of CH that interacts with inter-chain disulfide bonds of 2S albumins and 11S globulins of QP (Abugoch et al. 2011). The uses of the QP films remain to be defined.

Quinoa Starch-Based Stabilizer for Pickering Emulsions

Pickering emulsion (PE) is stabilized by solid particles. The small size (0.5–3 μm in diameter) and narrow size distribution of QS granules are useful to reduce the amount of starch per millilitre of oil required to stabilize a given emulsion droplet interface (Rayner et al. 2012a). Unlike the steric barrier functions of hydrocolloids, hydrophobically modified QS granules can be absorbed to the oil-water interface, granting the excellent stability and barrier properties to the PE (Repo-Carrasco et al. 2003; Timgren et al. 2011; Rayner et al. 2012a, 2012b; Matos et al. 2013).

To increase the hydrophobicity of QS, physical modification (i.e. dry heating for modifying the surface proteins of starch granules) appeared less efficient to stabilize PE than chemical modification (i.e. *n*-octenyl succinic anhydride (OSA) modification) (Rayner et al. 2012b). Among three different degrees of OSA modification (1.95, 3.21 and 4.66 %), 3.21 % was the most efficient for PE stabilization (Fig. 2). A higher degree of modification (4.66 %) led to aggregation of QS granules, while a lower degree of modification (1.95 %) failed to provide enough hydrophobicity (Rayner et al. 2012b). Matos et al. 2013 successfully produced QS double water-in-oil-in-water (W1/O/W2) emulsion with over 98.5 % initial encapsulation efficiency. The W1/O/W2 PE had 8.25 % (*v*/*v*) internal water phase (W1) containing carmine dye and NaCl, 33 % *v*/*v* oil phase (O) containing 1.8 % OSA-modified QS (214 mg/mL Miglyol812 oil) and 58.75 % (*v*/*v*) outer water phase (W2) containing sodium phosphate buffer (5 mM, pH 7.0) and NaCl (0.2 M). The W1/O/W2 had

encapsulation stability of over 90 % after 21 days storage at room temperature. The encapsulation efficiency measured the initial amount of carmine dye lost from the W1 phase into the W2 phase during the emulsification process. The encapsulation stability measured the amount of carmine dye leaking from the internal W1 phase into the outer continuous W2 phase during storage. Around 95 % encapsulation efficiency and 70–80 % encapsulation stability (after a few weeks' storage) indicates a good stability of double PE (Matos et al. 2013). PE stabilized by QS remains to be applied in actual food systems.

Conclusions

Quinoa flour and seeds have been incorporated into bread (sourdough or non-sourdough), Chinese steamed bread, pasta (spaghetti or tagliatelle), snacks and cookies to enhance their nutrition values. Compared with WF products, the physicochemical properties of the quinoa-containing intermediate and finished products were affected by addition level to various extents. For gluten-free food such as pasta, diverse structuring agents were employed to counteract the detrimental effect of quinoa addition on the quality due to gluten matrix dilution. The eating quality of some quinoa-containing food products may still be acceptable as evaluated by panelists, depending on the product type and substitution level. Foods with much altered physiochemical properties and accepted sensory quality may be categorized as novel quinoa products. Quinoa starch and quinoa protein-chitosan composite films as well as quinoa starch-stabilized Pickering emulsions have been developed.

There is a lack of information on the glycemic profile of quinoa products, as quinoa starch appears to be easily digested. Gluten free products with a low glycemic index can be desirable, as in some cases, diabetes and celiac diseases occur together. A comprehensive approach should be employed to assess diverse quality attributes of the quinoa-containing products. Some attributes such as dietary fibre composition, sensory data and consumer acceptance of the resulting products appeared to be lacking. Non-conventional products developed as novel products should also be tested for the feasibility in actual food applications. Apart from seeds, other parts of quinoa plant including stalks, leaves and roots could be explored for manufacturing value-added products.

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