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COMPREHENSIVE REVIEWS

A review of the nutritional composition, organoleptic characteristics and biological effects of the high oleic peanut

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Abstract

A growing body of literature has been published on the health benefits of peanuts, but the potential biological effects of high-oleic (HO) peanuts, along with their organoleptic characteristics have not been reviewed to date. In this paper, examination of evidence showed that HO peanuts provide a spectrum of nutrients and have improved sensory properties and technological advances, such as enhanced shelf life, beyond that of conventional peanuts. This may be attributed to their oleic to linoleic ratio (OL ratio) which is substantially (around 10 times) higher than normal peanuts. In terms of their biological effects, HO peanuts appear to be no more allergenic, and could even be less allergenic than conventional peanuts. There is also emerging evidence that HO peanuts may improve lipid profile and markers of glycemic control. Further randomized controlled human trials are now needed to build on animal and *in vitro* studies.

Keywords

Comprehensive review, fatty acids, healthy benefits, nutritional properties, sensory characteristics

History

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Background

Peanuts (*Arachis hypogaea* L.) are among the major oilseeds in the world (Campos-Mondragon et al., 2009), containing a spectrum of nutrients, including unsaturated fatty acids, vegetable protein, fiber, tocopherols, phytosterols and phenolic compounds (Ros, 2010), while also being one of the most widely used legumes due to their taste (Akhtar et al., 2014). In turn, a growing body of literature has associated their consumption with an array of health benefits including reduced risk of coronary heart disease (CHD), gallstones and cholesterol-lowering effects, with emerging beneficial effects on oxidative stress and inflammation (Ros, 2010). Now further publications need to separate out the health benefits of peanuts from tree nuts, as there is a tendency to include both in studies and review papers.

The peanut kernel contains ~52% oil by weight which is rich in monounsaturated (MUFA) and polyunsaturated (PUFA) fatty acids (USDA, 2013). Of late there has been growing evidence in relation to the potential health and technological benefits of high-oleic (HO) peanuts, due to these having a substantially higher ratio of oleic to linoleic acid and containing around 80% and 2% oleic and linoleic fatty acids respectively, compared with 52% and 27% in standard peanuts (Isleib et al., 2006). In particular, fatty acid analysis by Isleib et al. (2006) showed that the oleic-to-linoleic acid ratio (OL ratio) was over 10 times higher for HO peanuts (5 HO lines used; 4 runner and 1 Virginia-type) when compared with normal peanuts, i.e. a ratio of 22 versus 2.13. This change in fatty-acid profile has namely been bought about by the incorporation of two recessive genes into breeding lines, yielding new HO varieties (Knauft et al., 1993; Moore & Knauft, 1989).

The main fatty acids found in HO peanut oil, are compared with conventional peanuts and other oils in Figure 1. This shows that HO peanuts contain the highest levels of oleic acid (more than 80%), yet lowest levels of linoleic acid, followed by olive oil, with other oils, including safflower, soya bean and sunflower oil containing the highest levels of linoleic acid. This also impacts positively on crop yield with HO peanuts such as Georgia-P6G yielding up to 5746 lbs per acre compared with conventional peanuts, producing around 3000 lbs per acre (AGMRC, 2013; Peanut, 2013). In contrast, in a sunflower field with a stand of 21 000 plants per acre, a head size of 7 inches and a medium seed size with good seed count of around 91 percent, the yield for sunflower oil would be approximately 1871 lbs per acre (NDSU, 2012).

Dietary surveys also provide useful information on current MUFA intakes. Data from the UK National Diet and Nutrition Survey shows that mean MUFA intakes were 12.5% food energy for adults and children aged 4–18 years and all were below the Dietary Reference Value (Pot et al., 2012). Survey data of Irish children and adults (0 to 30 years) also indicates that children's percent energy from MUFA has decreased significantly from 1978 (14.1%) to 1994 (11.9%), with the intake of oleic acid decreasing from 33.9 g/day (1973) to 25.7 g/day (1994) (Nicklas et al., 2004). Survey data also provides important information about food sources of MUFA. For example, whole milk and peanut butter appear to be some of the main MUFA sources in children and ground beef in adults (Nicklas et al., 2004). More specifically, with regard to nut intakes, the US National Health and Nutrition Examination Survey (NHANES) reported that around 19% of 19–50 years old adults consumed nuts (tree and peanuts) and 21% of adults aged 51 years or older (O'Neil et al., 2011), which may help contribute to MUFA intakes. This is useful

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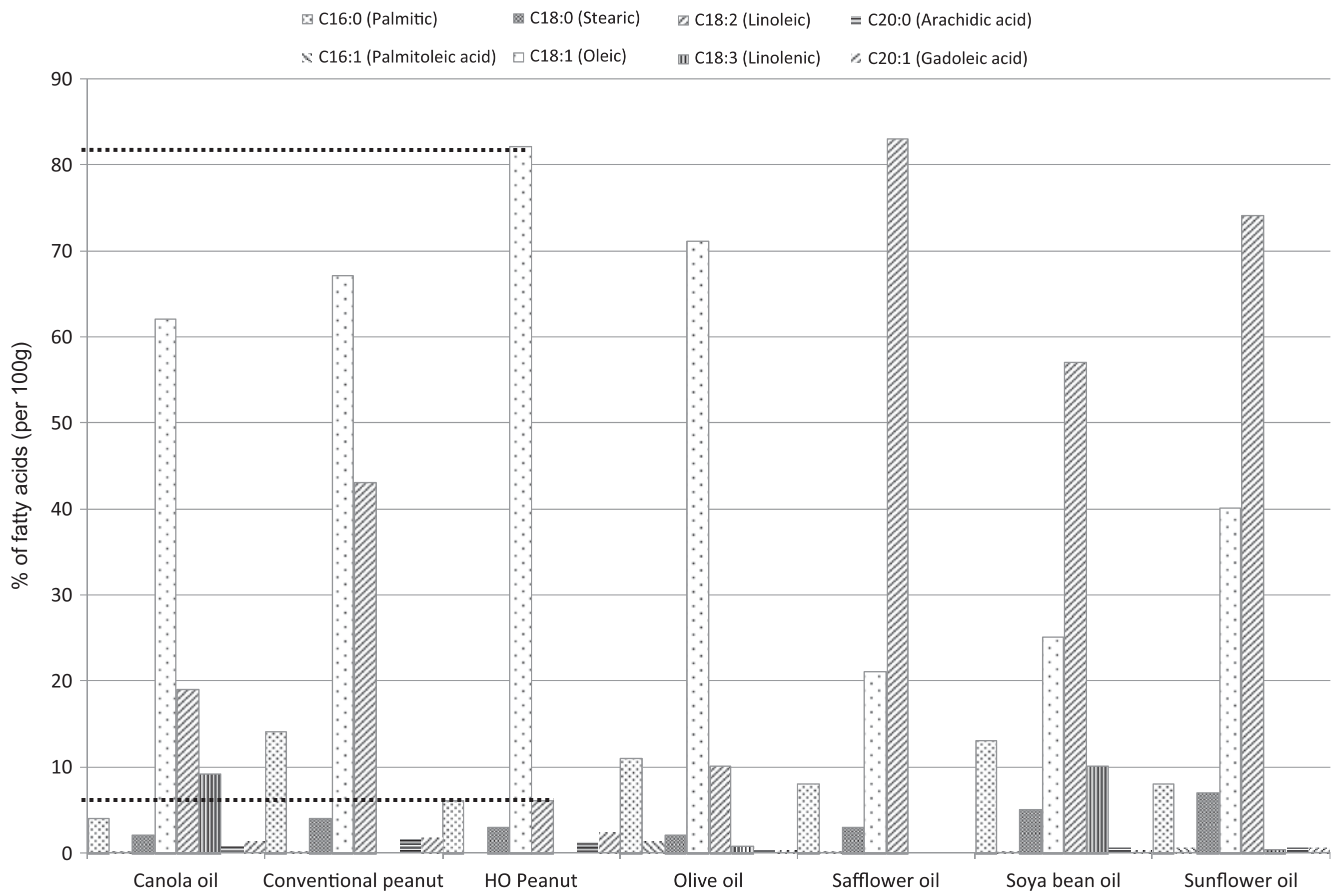

Figure 1. Content of major fatty acids found in high-oleic peanuts compared with other oils. Source: Data extracted/adapted from USDA (2013); Sakurai & Pokornỳ (2003).

information but data, ideally, should be separated for different nut varieties.

A large body of literature has been published on the health benefits of MUFA-based diets which have been linked to increased high-density lipoprotein cholesterol and reductions in triacylglycerols, systolic and diastolic blood pressure (Schwingshackl & Hoffmann, 2012). However, further long-term interventions are needed to confirm their efficacy among general and clinical populations. This will also help to support the formulation of dietary recommendations, for which unanimous guidelines are currently lacking (Schwingshackl & Hoffmann, 2012).

In terms of MUFA sources, until recently olive oil was one of the richest sources of oleic acid (Figure 1), which has reported beneficial effects on cancer, autoimmune and inflammatory diseases (Sales-Campos et al., 2013). Oleic acid is thought to have anti-inflammatory properties that activate different pathways of immune competent cells (Carrillo et al., 2012). Whilst oleic acids have been reported to have anti-inflammatory effects, linoleic acid is a metabolic precursor to arachidonic acid and eicosanoids which have been associated with an increased risk of inflammation, cancers, CV disease and neurological disorders (Whelan, 2008). Adulterated forms of linoleic acid, in particular, such as hydrogenated vegetable oils are regarded as atherogenic and are not considered part of a healthy diet (Anton et al., 2013).

From a manufacturing stance, the oxidative stability of peanuts has been found to be substantially (3.4 to 14.5 times) greater for HO peanuts than regular peanuts, with variations generally depending on measurement methods used (O'Keefe et al., 1993). In one study, oxidative stress index (OSI) values (a measure of product stability) for HO peanuts after 20 weeks of storage were found to be similar to OSI values for conventional peanuts immediately after roasting. This indicates that HO peanuts roasted in HO oil had a longer shelf life than those roasted in standard peanut oil. Therefore, combining the use of HO peanuts and HO peanut oil appears to have the greatest technological benefits for food processors, helping full shelf-life potential to be achieved (Bolton & Sanders, 2002). From a technological stance, the OL ratio is a useful indicator of a products stability and shelf-life index (Isleib et al., 2006).

This is important considering that unsaturated fatty acids, particularly those with more than two double bonds, have the ability to oxidize rapidly (Kouba & Mourot, 2011). This can lead to lipid peroxidation and indirect formation of aliphatic aldehydes, ketones and alcohols associated with rancidity and off-flavors in peanut products (St Angelo, 1996). It is well recognized that peanut paste and butter with high oil contents are prone to developing rancid and off-flavors due to lipid oxidation (Riveros et al., 2010). Rancidity and lipid peroxidation also contribute to cell membrane damage which has been linked to a variety of pathological conditions (Comporti, 1993). It is thought that the high ratio of oleic to linoleic acid could improve the oxidative stability of HO peanuts (Bolton & Sanders, 2002; O'Keefe et al., 1993). Equally, antioxidant compounds present and formed when HO peanuts are roasted may further reinforce this (Bolton & Sanders, 2002).

Taken together, the literature base to date has shown recent interest in associations between peanuts and health, however, few studies have directly investigated the effect of HO peanuts. Taking this on board, this article aims to review the nutritional composition, organoleptic properties and biological effects of HO peanuts in relation to human health.

Methods

Identification of relevant studies

Medline (PubMed), Web of Science and Science Direct were searched for English-language, peer reviewed studies published between January 1993 and April 2014, with the last database check undertaken on 30 April 2014 (Figure 2). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses Guidelines was used as a guide to the weight placed on studies (Moher et al., 2009), with randomized controlled trials, intervention, *in vitro* studies, chemical analysis and animal studies being included.

The search was limited to studies looking at high-oleic peanuts. The keyword search terms used in all of the databases included: ''high-oleic peanut'' in combination with ''nutrients'', ''antioxidants'', ''fatty acids'', ''organoleptic/sensory properties'', ''taste'', ''texture'', ''astringency'', ''aroma'', ''stability'', ''shelf life'', ''consumer acceptability'', ''health'', ''cardiovascular disease'', ''diabetes'', ''weight'' and ''satiety'' which were each combined using the Boolean ''AND''. The reference lists of scientific papers and reports were also hand searched and relevant papers identified.

Inclusion criteria and screening protocol

Inclusion was based on the following criteria used when selecting studies: (i) papers using HO peanuts/HO peanut oil, (ii) the peanut cultivar used or oil content was clearly specified, (iii) the publication was a journal and scientific study and (iv) access to the full paper was available, either through the search engines used, contacting the author, or ordering the full text.

In terms of identifying the studies included in the review, the protocol included: screening the identified papers using the abstract, removal of duplicate papers, further examination for relevance using full text and cross-checking to ensure the study was in line with the inclusion criteria.

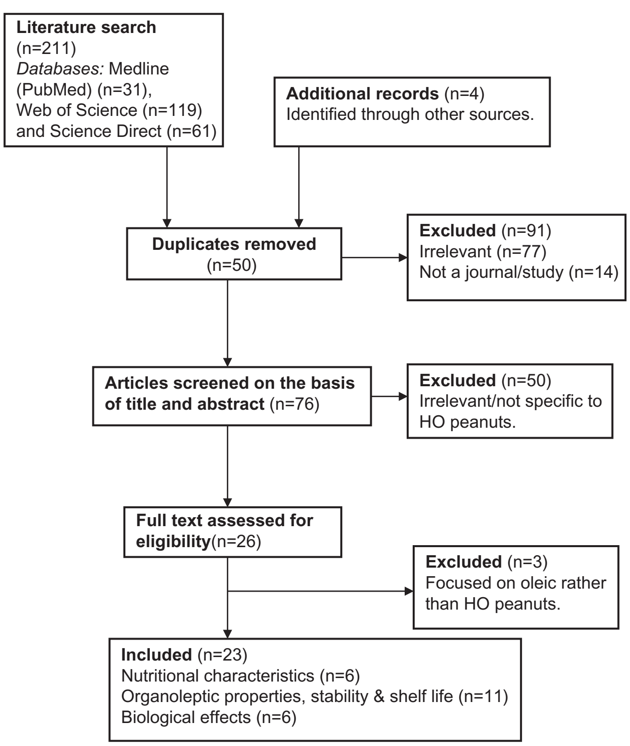

Figure 2. Procedures for database searches and publications identified.

Results

As shown in Figure 2 a total of 211 papers were identified from database searches and a further 4 from reference lists of scientific papers and reports. Forty-eight papers were excluded for being duplicates and a further 91 excluded because they were irrelevant or not a scientific study/journal. This left a total of 23 papers meeting the inclusion criteria, displayed in Table 1. Of the 23 studies found, six investigated the role of HO acid in relation to their nutritional properties, 11 on the organoleptic, stability and shelf life properties of HO peanuts and six on their biological effects.

Nutritional composition

From the scientific search undertaken, six studies investigated the nutritional composition of HO peanuts. Of these, four measured the tocopherol content of HO peanuts (Davis et al., 2008; Isleib et al., 2006; Jonnala et al., 2005, 2006), with others measuring their sugar and sucrose content (Isleib et al., 2006), calcium, potassium and phosphorous profile (Jonnala et al., 2005), or *p*-Coumaric acid; a hydroxycinnamic acid found in plant sources such as peanuts with antioxidant properties (Craft et al., 2010; Talcott et al., 2005).

While the potential health benefits of a higher OL ratio have already been mentioned, eating a higher frequency of foods containing sucrose has been linked to the development of dental caries (Anderson et al., 2009) while vitamin E is regarded to be essential for human health, playing a role in the prevention of certain degenerative diseases (Borel et al., 2013). Isleib et al. (2006) used Uniform Peanut Performance Tests (UPPT); a series of physical, sensory and compositional tests to assess the quality of HO and normal peanuts. Analysis of these different peanut varieties showed that whilst the OL ratio was found to be significantly higher for HO peanuts compared with standard peanuts (22.02 versus 2.13), the total sugar content and sucrose content was also found to be significantly lower for HO peanuts (Isleib et al., 2006).

Isleib et al. (2006) also measured the tocopherol content of peanut paste samples, finding that while total and α- tocopherol levels were significantly lower for HO compared with normal peanuts, γ and δ-tocopherol fractions were significantly higher for HO peanut varieties. Davis et al. (2008) also found that two of three HO peanut varieties were significantly higher in their total tocopherol content compared with standard peanuts and Jonnala et al. (2006) concluded that HO peanuts were a rich source of α-tocopherol.

However, a number of factors should be considered when interpreting the findings from these studies. Firstly, different growing regions may have affected tocopherol levels. For example, Hashim et al. (1993) found that drought stress led to significant reductions in α-tocopherol levels of Florunner peanuts. Secondly, the UPPT used by Isleib et al. (2006) is subject to limitations in that it lacks uniformity when used at different locations with varying cultural practices. Thirdly, methods used in work by Isleib et al. (2006) were developed with the intention of preventing oxidation of the peanut paste. This is likely to have preserved the tocopherol content of normal peanuts, possibly skewing data findings. Overall, it appears that the tocopherol content is the same or higher in HO peanuts when compared with standard oleic peanuts, although factors such as the peanut source, growing region and study methods may influence tocopherol content.

Polyphenolic compounds are also thought to offer health benefits, namely through their antioxidant properties, i.e. their ability to scavenge free radicals and induce the production of endogenous protective enzymes (Stevenson & Hurst, 2007). Some

Table 1. Studies investigating the nutritional composition, organoleptic characteristics and biological effects of the high oleic peanut.

Reference	Study design	Peanut cultivar	Findings
Nutritional composition			
Talcott et al. (2005)	Chemical analysis. Antioxidant capacity measured.	Eight cultivars with either HO or normal oleic content.	Peanuts were found to be a good source of antioxidant polyphenols, including ρ-coumaric acid.
Isleib et al. (2006)	Secondary analysis of data from US flavor databases. Nutritional composition (oil composition, tocopherol & carbohydrate) of HO versus normal peanut genotypes compared.	16 genotypes tested (HO & normal).	The OL ratio was significantly higher for HO vs conventional peanuts (22 versus 2). Total sugar, sucrose and tocopherol content were significantly lower in HO peanuts.
Jonnala et al. (2005)	Chemical analysis. Mineral content analysis.	Tamrun (OL 01), Tamrun (OL 02), TX977164 and TX977239 HO peanut cultivars.	Peanut seeds were rich in potassium whilst phosphorus & calcium were the other major minerals found in all peanut samples.
Jonnala et al. (2006)	Chemical analysis. Modified peanut lines analyzed for their tocopherol, phytosterol & phospholipid compositions.	Tamrun (OL 01), Tamrun (OL 02), TX977164, TX977239 HO peanut cultivars.	Compared to parent lines (acting as controls) these peanut lines were rich in α-tocopherol, phytosterols (especially Tamrun OL 01) and phosphatidylcholine.
Davis et al. (2008)	Chemical analysis. Tocopherol analysis of nine HO versus normal cultivars.	Nine cultivars of peanut.	Two of three of the HO oils from peanut cultivars had the significantly highest ($p<0.05$) tocopherol content.
Craft et al. (2010)	Chemical analysis. Phenolic compounds extracted using 80% methanol and analyzed using HPLC.	309 peanut samples including Runners, Virginias, Gregory OL & HO varieties of Runner & Spanish peanuts TamRun (OL01 and OLIN).	A HO runner had the greatest ↑ (785%) in free ρ-coumaric acid levels after oil roasting.
Organoleptic characteristics, stability and shelf-life			
Myer et al. (1992)	Animal study & sensory panel. $n=48$ pigs allocated to corn-soybean meals containing: (1) HO peanuts, (2) regular peanuts or (3) canola oil until they weighed 102 kg. Trained panelists ($n=9$) evaluated meat samples.	The HO peanut oil was 75% oleic, versus 60% for canola oil and 53% for regular peanuts.	Sensations of 'off flavors' were found to be reduced when meat from swine fed a diet rich in HO peanuts was tasted.
Braddock et al. (1995)	Trained panel ($n=20$) for sensory evaluation.	HO new peanut line (developed by University of Florida) versus normal peanut.	Painty & cardboard flavors were more stable than normal for HO peanuts after 6 weeks of storage. Shelf life estimated from sensory data was twice as long in HO peanuts.
Pattee & Knauft (1995)	Trained panel ($n=8$) for sensory evaluation.	Peanut paste was tested from for HO acid breeding varieties (F1250, F1315, F1316, F1334), Florunner and NC 7.	F1316 and F1334 had higher roasted peanut intensities than other HO breeding lines.
Mugendi et al. (1998)	Sensory evaluation ($n=13$) (peanutty flavor, sweetness, crunchiness & oxidized flavors).	HO peanut (F1250, BC93Q10) and normal oleic peanut (Florunner)	HO peanuts had better flavor quality & stability than the normal oleic peanut, which oxidised faster and developed painty off-flavors.
Baker et al. (2002)	Sensory analysis conducted every 2 weeks, for 14 weeks after storing HO peanuts under different water activities.	HO peanuts (from the University of Florida breeding programme).	Roasted HO peanuts maintained best product quality (i.e. desirable flavors) when stored at water activities between 0.33 and 0.44. Above this range crunchiness ↓ and oxidation ↑.
Bolton & Sanders (2002)	HO peanuts (O/L ratio 30.0) 110 g roasted samples were analyzed for their moisture content, water activity and oxidative stability index.	HO peanuts obtained from Golden Peanut Co, Atlanta.	Shelf life of HO peanuts ↓ when roasted in conventional peanut oil versus HO peanut oil.
Chung et al. (2002)	The end-product adducts of raw and roasted HO and normal peanuts was measured.	Florunner, Georgia Green, NC 9, NC 2.	MDA ↑ but not in HO peanuts indicating that HO peanuts are more stable to lipid oxidation.
Pattee et al. (2002)	Sensory, trained panellists ($n=9$.) using a 14-point flavor intensity unit (fiu) scale.	Normal and HO variants tested (F435, GK 7, NC 7, Sunrunner, Tamrun 96, Tamspan 90).	The HO trait ↑ the intensity of the roasted peanut attribute but ↑ the bitter attribute in Spanish genotypes.

Isleib et al. (2006)	Secondary analysis of data from US flavor databases. Sensory quality of HO versus normal peanut genotypes compared.	Sensory attribute intensities from 16 genotypes tested (HO & normal).	The HO trait did not appear to have a major impact on sensory quality, although there were individual instances in which the trait was associated with shifts in sensory attribute intensities that may be perceptible to consumers.
Nepote et al. (2009)	Consumer panel ($n = 100$) and trained panel ($n = 12$)	Consumer acceptance of 16 genotypes tested (HO & normal)	HO genotypes 4896-11-C and 9399–10 were highly accepted by consumers, ranking 7 in a hedonic scale of 9.
Riveros et al. (2010)	Trained panellists ($n = 10$) evaluated sensory profiles.	HO (cv. Granoleico) and normal (cv. Tegua) used.	Intensity of oxidised flavor was significantly higher for normal peanuts except for samples stored at 4 °C. Intensity rating of cardboard flavor was also significantly higher for normal peanuts. Sensory intensities of a roasted peanutty flavor were also significantly lower for normal peanuts.Chemical measurements of PV, AV and CD showed that peanut paste prepared with HO peanuts had a longer shelf life than that made with normal peanuts.
Biological effects			
Myer et al. (1992)	Animal study. $n = 48$ pigs allocated to corn-soybean meals containing: (1) HO peanuts, (2) regular peanuts or (3) canola oil until they weighed 102 kg.	The HO peanut oil was 75% oleic, *versus* 60% for canola oil and 53% for regular peanuts.	The HO peanut diet led to the greatest ↑ in MUFAs in the backfat (32% greater than the control). Total unsaturated fat content ↑ significantly by 24% after the HO peanut diet without affecting meat quality characteristics.
O'Byrne et al. (1997)	Intervention study. $n = 20$ postmenopausal hypercholesterolemic F previously eating high-fat diets ate a LFMR diet for 6 months. LFMR subjects ate 35-68 g HO peanuts per day. $n = 16$ F eating LF diets were also followed.	HO peanuts (from the University of Florida breeding programme).	Serum cholesterol ↓ 10% and LDL-C ↓12% in the LFMR diet compared with the LF diet. The LFMR group showed beneficial changes in LDL-C/HDL-C and apo-A versus apo-B ratios.
Chung et al. (2002)	*In vitro* study. Allergenicity measured by determining IgE binding and T-cell proliferation. Lipid peroxidation levels measured using MDA.	Four different peanuts compared with HO peanuts (SunOleic 97R).	After roasting MDA ↑ 2-fold in standard peanuts but no changes in MDA were seen in HO peanuts suggesting they are more stable to lipid oxidation during heating. Little differences found in IgE binding & T-cell proliferation indicating that HO peanuts have no greater adverse allergenic effects than normal peanuts.
Yamaki et al. (2002)	Animal study (mice). Diet containing 10% oil was fed to mice with lung induced tumorigenesis.	10% HO oil in the diet.	Feeding HO ↓ lung tumour incidence & tumour multiplicity (percentage of mice with tumours) in mice compared with LA feeding at the 20th experimental week. Findings suggest that HO acid suppresses lung tumorigenesis which is correlated with the inhibition of PGE_2 production and inactivation of the Erk cascade.
Huong Nguyen et al. (2003)	Chemical analysis (electrophoresis & western blotting) and an *In vivo* study. $n = 5$ (2 patients with peanut allergy; 3 nonallergenic controls). Skin prick tests undertaken to detect IgE binding to different peanuts.	33 raw peanuts, different varieties compared with HO peanuts (SunOleic, Florunner 458).	An ↑ threshold sensitivity of HO peanuts, at least 5x that of standard peanuts was found using an oral food challenge test. HO peanuts may provide ↓ sensitization to allergens.
Vassiliou et al. (2009)	*In vitro* and *In vivo* (animal) study. Rat pancreatic beta cell lines were grown for the *In vitro* study & mice were fed control, high fat or peanut oil diets for 7 days, followed by being administered peanut oil by gavage for 21 days for the *In vivo* study.	Normal oleic and two HO peanuts oils were used.	Peanut oil high in oleic acid was found to ↑ insulin production & reverse the inhibitory effect of TNF-α. HO peanut oil had a beneficial effect in T2D by ↓the negative effects of markers of inflammation, namely inflammatory cytokines which are commonly observed in obesity & non insulin dependant diabetes.

Key: AV, ρ-ansidine value; CD, Conjugated dienes; cv. cultivar; Erk, extracellular signal-regulated kinase; F, females; HDL-C, high-density lipoprotein cholesterol; HO, high-oleic; MDA, LA, linoleic acid; LDL-C, low-density lipoprotein; LF, low-fat; LFMR, low fat-monounsaturated fat rich; MDA, malondialdehyde; MUFAs, monounsaturated fatty acids; OL ratio; oleic-to-linoleic ratio; PV, peroxide value; T2D, type II diabetics; TNF, tumor necrosis factor: PGE2, prostaglandin 2.

studies have also shown that HO peanuts provide a greater source of hydroxycinnamic acids, which have been associated with health benefits such as reduced risk of CV disease (El-Seedi et al., 2012). Talcott et al. (2005) analyzed the polyphenol content of eight peanut cultivars, four of which were HO peanuts, finding these to be a good source of *p*-Coumaric acid. Similarly, Craft et al. (2010) used Reverse Phase-High Performance Liquid Chromatography (HPLC) to determine the *p*-Coumaric acid content of 15 samples of peanuts. The HO-Runner (TamRun OL02) was found to have the greatest increase (~785%) in free *p*-Coumaric acid levels after roasting. It has also been proposed that free *ρ*-coumaric acid levels in peanuts may lead to decreased levels of peanut allergenicity, possibly because hydroxycinnamic acids can bind the peanut allergens Ara h 1 and Ara h 2 (Chung & Champagne, 2009).

Finally, Jonnala et al. (2005) measured the chemical composition of five HO peanut cultivars, finding their peanut seeds to be 42 to 49% oil, 29% protein, 9 to 12% dietary fiber, 2% ash and 5% moisture, with all being rich in potassium and found to contain phosphorous and calcium. Peanuts themselves have been associated with appetite regulation due to their MUFA and PUFA content which is thought to have a stronger satiety value than saturated fats (Iyer et al., 2006). It is also well documented that dietary fibers have the ability to regulate appetite, especially viscous fibers (Kristensen & Jensen, 2011). Given recent evidence showing that peanut butter ingestion, and the inclusion of whole peanuts to breakfast helped to improve glucose levels and regulate appetite in obese women (Reis et al., 2013), it would certainly be worthy to study the potential satiety effects of HO peanuts given their higher OL ratio and favourable fibre content (Isleib et al., 2006; Jonnala et al., 2005).

Jonnala et al. (2006) using the same varieties of peanuts and HPLC methods found that HO peanuts were a good source of phosphatidylcholine (PC). PC is a major component of cell membranes and thought to play a role in determining cell fate (Ridgway, 2013). It is also needed for lipoprotein assembly and secretion, with impaired PC being associated with disruptions in lipoprotein metabolism, namely reduced levels of circulating very low-density and high-density lipoproteins (Cole et al., 2012).

To this end, it seems that HO peanuts are a valuable food crop, containing a host of nutrients and bioactive components that have their own separate health benefits. It is well established that HO peanuts are a good source of healthy unsaturated fats, containing a significantly higher ratio of oleic to linoleic acid (Bolton & Sanders, 2002; Isleib et al., 2006; Nepote et al., 2009; Shin et al., 2010) compared to regular peanuts. HO peanuts contain antioxidants both in the form of tocopherols (Davis et al., 2008; Isleib et al., 2006) and *p*-Coumaric acid (Talcott et al., 2005; Craft et al., 2010), fiber with an array of minerals and PC (Jonnala et al., 2005).

Organoleptic characteristics, stability and shelf life

It is widely accepted that sensory properties of foods, i.e. exposure to the sight, smell, taste and textural attributes can stimulate a spectrum of digestive, endocrinologic, thermogenic, cardiovascular, and renal responses, each with their own potential physiological effects (Mattes, 1997). From the scientific database searches, eleven studies were found investigating the organoleptic, stability and shelf-life properties of HO peanuts.

In one of the earliest studies, the sensory properties of HO peanuts were not measured directly. Instead, trained panellists tasted meat from swine reared on a HO peanut-based diet, regular peanuts or corn oil. Interestingly, the MUFA profile of meat was found to be highest for animals fed the HO peanut diet and when tasted by a sensory panel was found to have fewer off-flavors than meat from swine fed with regular peanuts or canola oil (Myer et al., 1992).

Seven other studies identified that HO peanuts have improved flavors to conventional peanuts (Baker et al., 2002; Braddock et al., 1995; Mugendi et al., 1998; Pattee et al., 2002; Riveros et al., 2010), with Nepote et al. (2009) reporting that HO peanuts were highly accepted by consumers, ranking 7 out of a hedonic scale of 9. As shown in Table 1, HO peanuts in general were found to have a better flavor quality, which included lower levels of painty, cardboard or oxidized flavors than regular peanuts. Only one study contested these findings (Isleib et al., 2006), with the HO trait not being associated with any changes in flavor or sensory quality. However, as noted earlier, the protocol used in this study was tailored to prevent the oxidation of the roasted peanut paste prior to sensory evaluation, which may have improved the flavor of conventional peanuts (Isleib et al., 2006).

Chemical indicators of lipid oxidation (peroxide and *ρ*-Anisidine values and conjugated dienes) were also found to be lower in HO peanut genotypes in work by Nepote et al. (2009). At this point it should be considered that oxidation affects peanut flavor, with the intensity of oxidized flavors generally being higher for normal versus HO peanuts (Riveros et al., 2010). Subsequently, as shown in Table 1, this may have played a role in reducing sensory appeal of normal peanuts. Similarly, Chung et al. (2002) also found that malondialdehyde (MDA) levels did not increase in HO peanuts, indicating that they are more stable to lipid oxidation than normal peanuts during heating.

A number of studies have investigated the shelf life of HO peanuts. Bolton & Sanders (2002) measured the shelf life potential of roasted HO peanuts after 20 weeks of storage, finding that HO peanuts roasted in a high oleic acid oil had a longer shelf life than those roasted in conventional oil. Additionally, work by Riveros et al. (2010) found that HO peanuts stored at 4 °C, 23 °C and 40 °C had four-, two- and three-times longer shelf life than peanut paste prepared with normal peanuts, due to increased resistance from lipid oxidation.

On the whole, a growing body of literature indicates that HO peanuts appear to be more widely accepted and have an improved sensory profile when compared with conventional peanuts. This appears to be attributed to their higher OL ratio, which is less susceptible to the effects of lipid oxidation. Also, antioxidant compounds present and formed when HO peanuts are roasted may further help to improve their oxidative stability (Bolton & Sanders, 2002). Taken together, these properties of HO peanuts appear to enhance shelf life, flavor and reduce sensations of oxidized flavors.

Biological effects

Non-communicable diseases (NCDs), such as CV disease, diabetes and cancer are not only confined to the developed world, as rates are also rising in low- and middle-income countries. This is largely attributed to urbanization, supermarket growth and increasingly sedentary lifestyles, which contribute to obesity, elevated blood and cholesterol levels. It is thought that improved diet quality, physical activity levels and the integration of nutrient-rich functional foods, or food ingredients may hold great promise in terms of preventing NCDs (Wagner & Brath, 2011).

Of the studies identified and presented in Table 1, six appear to have investigated the role of HO peanuts, or HO peanut oil in relation to biological markers of health. Of these, one was a human intervention study, two were animal studies, and three were *in vivo* or *in vitro* studies. Of these, two studies investigated the allergenic properties of HO peanuts (Chung et al., 2002; Huong et al., 2003). While it is well recognized that peanuts in general are allergenic with Ara h 2 and Ara h 6 proteins being regarded as the main peanut allergens (Zhuang & Dreskin, 2013) less is known about the allergenic properties of HO peanuts.

According to work by Chung et al. (2002) HO peanuts were found to be no different than normal peanuts in terms of their allergenic properties, which could be attributed to their lower linoleic acid content (around 2% compared with 25% in normal peanuts). This theory is supported by epidemiological evidence which has shown that countries with a lower dietary linoleic acid intake, e.g. Asia have a lower risk of allergic disease (ISAAC, 1998). In particular, Chung et al. (2002) used *in vitro* methods to compare levels of IgE binding and T-cell proliferation in four types of conventional peanut and a HO peanut (SunOleic 97R) variety. As allergens are typically defined as antigens that elicit an IgE response (Zhuang & Dreskin, 2013) this approach was thought to identify which peanut cultivars contained the highest levels of allergenic proteins. Scientists concluded that HO peanuts did not differ from normal peanuts in terms of eliciting an IgE binding and T-cell response. Possible mechanisms include linoleic acid acting as a precursor of prostaglandin E_2 which can increase the body's sensitivity to producing antibodies when exposed to antigens, exacerbating allergic responses (Chung et al., 2002).

Other work suggests that HO peanuts may contain lower levels of protein allergens, which can delay an allergic response, or lower the risk of the severity of a reaction. For example, research carried out by Huong et al. (2003) showed that the threshold of sensitivity to high-oleic peanuts was at least five times higher than other peanuts. In addition, the ingestion of 5 HO (SunOleic) roasted peanuts did not elicit signs of an allergic reaction in a mild-peanut allergic patient when compared with the ingestion of 1 normal oleic peanut that did show signs of an allergic reaction (Huong et al., 2003). Overall, these findings indicate that HO peanuts may contain lower levels of protein allergens, which may delay the allergic response, or lower the risk of the severity of a reaction.

An emerging body of evidence has also investigated whether the HO peanuts can modulate lipid profiles and markers of glycemic control (O'Byrne et al., 1997; Vassiliou et al., 2009), both which have broader implications in terms of their associations with CV disease and diabetes (Sattar, 2013; Schwingshackl & Hoffmann, 2012). For example, work carried out by O'Byrne et al. (1997) found that a low-fat but MUFA-rich (LFMR) diet containing HO peanuts (35–65 grams daily for 6 months) significantly improved the serum lipid and apoplipoprotein profile of postmenopausal women with hypercholesterolemia. In particular, serum cholesterol levels were 10% lower, low-density lipoprotein (LDL) cholesterol levels were 12% lower and there were beneficial changes in the A-1/apo B ratio by the end of the study (O'Byrne et al., 1997). However, while this study shows potential benefits in terms of including HO peanuts within low-fat diets, further work is needed to separate out the effects of the interventions, i.e. both low-fat diets and HO peanuts were used in this trial. Also, there are concerns that low-fat diets themselves may impact on health, given that they have been an important ingredient in Western and non-Western diets for centuries (Feinman, 2010).

An animal study carried out on obese, non-insulin dependent type 2 diabetic mice given HO peanut oil also found that this to have anti-diabetic and anti-inflammatory properties (Vassiliou et al., 2009). In particular, HO peanut oil was found to increase insulin production, improve blood glucose levels and reduce markers of inflammation (Vassiliou et al., 2009). Following on from this, it would be of value to study the effects of HO peanut ingestion on markers of glycemia and inflammation using human models.

Other findings have shown that HO peanut oil may help to reduce the incidence of lung tumors in mice, possibly by inhibiting prostaglandin E_2 production which acts as a promoter in several types of cancers and via inactivation the Erk cascade (Yamaki et al., 2002). Another study found that feeding swine HO peanut oil changed the fatty acid profile of their meat, with back fat MUFA levels being around 32% higher than controls, with meat from animals fed a HO diet also having less off-flavors than those fed regular peanuts or canola oil (Myer et al., 1992).

Taken together, there appears to be an emerging body of evidence, namely from small intervention, animal and *in vivo* or *in vitro* studies indicating that HO peanuts, HO peanut oil and relative changes in the fatty acid profile of the diet could help to improve lipid profile and markers of glycemic control while being no different from normal peanuts in terms of their allergenic properties. The next stages should be to undertake human randomized controlled or crossover trials investigating the potential allergenic, cardiovascular, diabetic and weight management benefits of HO peanuts specifically to see how these compare with conventional peanuts.

Future directions

As described in the previous sections, HO peanuts seem to have great potential in terms of their improved sensory profiles, longer shelf life and emerging biological health effects. In particular, we have seen that HO peanuts have a substantially higher ratio of oleic to linoleic acid (around ten times higher) and contain around 80% and 2% oleic and linoleic fatty acids, compared with 52% and 27% in standard peanuts (Isleib et al., 2006; Norden et al., 1987).

We have also seen in the present review that HO peanuts appear to have improved sensory characteristics. This is largely because they are more stable when facing oxidative processes, due to their higher oleic and antioxidant content when compared with conventional peanuts. Also, given that a large proportion of peanuts are used in the domestic food industry (Riveros et al., 2010) there appears to be potential to add HO peanuts to other products to improve their own sensory properties. For example, in one study, peanut butter was added to biscuits which was found to improve both their fatty acid composition and level of acceptability when assessed by a sensory evaluation panel (Gajera et al., 2010). Peanut milk and peanut milk-based products such as tofu have also been produced since the 1950s (Diarra et al., 2005) and their could be a scope to use HO peanuts in these products.

Also, given the large amounts of waste peanut processing by-products, ways to utilize this are needed (Zhao et al., 2012), particularly as these are a source of important functional compounds. Isolating under-utilized peanut by-products such as hulls, skins and leaves to create new products containing bioactive compounds could help create new market opportunities, also increasing the value of agricultural residues (Francisco & Resurreccion, 2008). It is possible that in the future, cereals, breakfast bars, biscuits and other products could possibly act as vehicles for HO peanut and by-product delivery, with improved taste, fatty acid profile and nutrient density being some of the possible outcomes.

Finally, in terms of biological effects, it is already well established that substituting diets rich in saturated fats with MUFA and PUFA (like oleic acid) may have a beneficial effects on cancer, autoimmune and inflammatory diseases (Carrillo et al., 2012; Sales-Campos et al., 2013) as well as reducing CV disease risk by lowering low-density lipoprotein, serum triglycerides and maintaining high-density lipoprotein in human blood plasma (Massaro et al., 1999; Perez-Jimenez et al., 2005).

Some researchers have investigated the potential health effects of different HO food sources. For example, in one trial 15 healthy adults aged 35 to 69 years were randomized to eat a diet rich in saturated fat for 5 weeks then one rich in MUFA (as HO sunflower oil) making up 20.3% of total energy for 10 weeks followed by a crossover. Study findings showed that factor VIIc (a blood clotting factor implicated in CV disease), low-density lipoprotein and triglyceride levels were significantly lower on the MUFA compared with the saturated fat diet (Allman-Farinelli et al., 2005). Clearly, further studies are needed to reconfirm these results but it appears that substituting foods high in saturated fat with HO sunflower oil and margarine could have favorable effects on blood lipids and factor VIIc. Another study conducted on ten children with Human papillomavirus-induced laryngeal papillomatosis (benign tumors in the larynx) provided with 2.5 ml HO safflower oil daily for eight weeks showed that the effects of HO safflower oil were only restricted to mildly/moderately aggressive papillomatosis and were less effective than conjugated-linoleic acid (Louw, 2012).

While human RCTs testing the effects of HO peanuts and indeed other HO food sources are limited, a larger body of evidence has studied the health effects of olive oil and subsequent oleic acid consumption. For example, in a recent one year intervention study 424 participants at high risk of CVD (aged 55 to 80 years) were provided with a 3-month supply of virgin olive oil (1 litre per week) or mixed nuts (30 grams per day, as 15 g walnuts, 7.5 g hazelnuts and 7.5 g almonds) and consumed these alongside a Mediterranean diet. Findings showed that biomarkers of foods supplied, i.e. oleic oand α-linolenic acids, were beneficially associated with the incidence, reversion and prevalence of MetS (Mayneris-Perxachs et al., 2014). Similarly, in a large cohort study higher olive oil use and levels of plasma oleic acid were associated with reduced stroke risk; with participants in the third tertile of plasma oleic acid having a 73 percent reduced risk of stroke (Samieri et al., 2011). The EUROLIVE randomized crossover study ($n = 200$) also found that after 3 weeks olive oil ingestion oleic acid levels in low-density lipoprotein significantly increased, while those of linoleic and arachidonic acid decreased. In turn, an inverse relationship between the oleic/linoleic acid ratio and biomarkers of oxidative stress was observed (Cicero et al., 2008). A study has shown that diets rich in oleic acid derived from olive oil may play a role in increasing rates of fat and carbohydrate oxidation, leading to increased energy expenditure postprandially (Jones et al., 2008).

Conclusions

The nutritional composition, organoleptic properties and biological effects of HO peanuts do not appear to have been reviewed elsewhere. Given evidence linking peanuts to improved biological markers of health, it is now important to consider the emergence of HO peanuts and the health benefits that these could offer.

Taking the evidence as a whole, HO peanuts appear to have a superior fatty acid profile when compared to conventional peanuts, with their oil being found to contain a higher ratio of oleic to linoleic fatty acids (around ten times higher than conventional peanuts). It is well recognized that MUFAs, but particularly oleic acid have an important role in health. This review has therefore identified that HO peanuts could contribute to some of these reported health benefits, namely by improving consumers dietary profile of fatty acids. However, given that the latest NHANES survey showed that only around 19% of 19–50 year olds and 21% of adults' aged 51 years or older consumed tree or peanuts (O'Neil et al., 2011) this highlights a clear need to communicate general health benefits of peanuts and emerging evidence for HO peanuts.

In terms of possible health claims, as guided by the European Commission (EC) the health claim *''replacing saturated fats in the diet with unsaturated fats contributes to the maintenance of normal cholesterol''* could also be made for both peanuts and HO peanuts (EC, 2013). Although, it should be considered that this claim can only be used for foods ''high'' in unsaturated fatty acids, as specified according to the updated 1924/2006 European Commission regulation. These state that claims that a food is high in unsaturated fat may only be made where *''at least 70% of the fatty acids in the product derive from unsaturated fat under the condition that unsaturated fat provides more than 20% of energy of the product''* (European Parliament and Council, 2010). Subsequently, peanuts and HO peanuts could be regarded as high in unsaturated fats.

As regards to other nutritional properties, HO peanuts also contain an array of nutrients, including fiber, tocopherols, phytosterols, ρ-coumaric acid, PC, calcium, potassium and phosphorous (Ros, 2010), with many of these being associated with their own individual health benefits. In the future, it is possible that the nutritional composition of HO peanuts could be further improved to enhance levels of these individual bioactive components, so these alone have physiological benefits.

From this review it also emerged that the high-oleic content, OL ratio and antioxidant profile of HO peanuts make HO peanuts more stable than regular peanuts when facing oxidation process. This, in turn, further helps to improve their shelf life and sensory properties, as evidenced by data from taste panels. Taking all of these points into consideration, when compared with conventional peanuts, HO varieties appear to have a superior nutritional profile, improved flavor and longer shelf life.

Next, new lines of research are necessary to build on the evidence that exists, particularly in the form of randomized controlled or crossover trials. Further to this, aspects such as the bioavailability of nutrients in HO peanuts, other bioactive constituents in the different components of the nuts and potential health benefits specific to HO peanuts are in need of investigation. That said, given the positive evidence that has emerged in recent years in relation to peanuts and health, and indeed, oleic acid this is an exciting and promising area worthy of study and future communication to public sectors.

Declaration of interest

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