Do dry roasting, lightly salting nuts affect their cardioprotective properties and acceptability?

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Abstract

Purpose Previous studies have reported improvements in cardiovascular disease (CVD) risk factors with the consumption of raw nuts. However, around one-third of nuts consumed are roasted and salted. Thus, it is important to determine whether roasting and salting nuts affect the health benefits observed with raw nuts. This study aimed to compare the effects of consuming two different forms of hazelnuts on cardiovascular risk factors and acceptability.

Methods Using a randomised crossover design, 72 participants were asked to consume 30 g/day of either raw or dry roasted, lightly salted hazelnuts for 28 days each. CVD risk factors were measured at the beginning and end of each treatment period. “Desire to consume” and “overall liking” for both forms of hazelnuts were assessed daily using a 150-mm visual analogue scale.

Results Body composition, blood pressure, plasma total and low-density lipoprotein-cholesterol, apolipoprotein A1 and B100, glucose and α-tocopherol concentrations did not differ between forms of hazelnuts (all $P \geq 0.054$). High-density lipoprotein (HDL)-cholesterol ($P = 0.037$) and triacylglycerol ($P < 0.001$) concentrations were significantly lower following the consumption of dry roasted, lightly salted hazelnuts when compared to the raw hazelnuts.

Conclusion Dry roasting and lightly salting nuts do not appear to negate the cardioprotective effects observed with raw nut consumption, and both forms of nuts are resistant to monotony. Public health messages could be extended to include dry roasted and lightly salted nuts as part of a heart healthy diet.

Keywords Hazelnuts · Roasting · Salting · Cardiovascular disease · Acceptance

Introduction

Cardiovascular disease (CVD) is one of the leading causes of mortality worldwide, with one-third of all global deaths [1] and 30% of all deaths in New Zealand attributed to CVD [2]. Nuts are naturally low in sodium and high in unsaturated fatty acids, dietary fibre, plant protein, phytochemicals, vitamins and minerals, some of which may act synergistically to produce a wide range of health benefits [3–5]. However, around a third of whole nuts consumed are roasted and salted [6]. Thus, it is important to determine whether processing nuts affects their health benefits. Presently, the National Heart Foundation of New Zealand recommends the regular consumption of 30 g of raw nuts on the basis of their cardioprotective effect [7]. Two studies reported that the palatability of roasted and salted nuts was significantly higher than raw nuts when measured in a single session [8, 9]. If health outcomes are not...
compromised, recommending consuming nuts in these more preferred forms may provide an effective approach to improving cardiovascular health among the general population. This is important given the results of several studies which have reported the prevalence of whole nut consumption on any given day to be only 6.9% in New Zealand (of which approximately half were roasted forms) [6], 6.9% in Europe [10] and 6.0% in the USA [11].

To our knowledge, only three clinical trials have compared the effects of consuming processed nuts on cardiovascular risk factors [12–14]. All three studies were conducted using a randomised, parallel design with intervention periods ranging from 4 weeks [13, 14] to 12 weeks [12]. Spiller et al. [14] used 100 g/day of raw almonds, roasted almond butter or roasted salted almonds (209 mg of sodium per 100 g), while the other studies used 42 g/day (salted, unsalted, honey roasted, spicy) [12] or 56 g/day (raw unsalted, roasted unsalted, roasted salted, honey roasted or butter) [13] of peanuts. These studies showed no significant differences in blood lipid profiles [12–14], blood pressure [12, 14], blood glucose and insulin [12] between different forms of nuts. It is important to highlight that the authors did not report the methods used for roasting nuts and these studies had relatively small sample sizes (n < 27 per single flavour treatment) and so might not have been adequately powered to detect small but clinically important effects. In addition, McKiernan et al. [13] did not report the between-groups analysis on blood pressure. Thus, it remains unclear whether roasting and salting nuts influence different health outcomes.

In addition to investigating the cardioprotective effects of nuts, it is also important to examine the acceptability and sustainability of the recommendation to consume nuts on a daily basis. To date, only four clinical trials have investigated the effects of regular consumption of raw hazelnuts on participants’ “desire” and “liking” [15–18]. These studies showed that daily consumption of between 30 and 42 g of raw hazelnuts for periods between 5 days and 12 weeks did not appear to result in monotony, i.e. a decline in acceptance over time. One recent study examined the “liking” for peanuts consumed as either a single flavour or a variety of flavours daily for 12 weeks [19]. This study reported a significant decline in liking for peanuts over 12 weeks, with no difference between the single and mixed flavours. However, the authors did not report the actual liking values for the different peanut flavours, which makes the interpretation difficult [19]. With the limited evidence to date, it is of interest to determine whether the sustained acceptance observed with raw nut consumption can be generalised to other forms of nuts, e.g. roasted and salted nuts.

The cardiovascular health benefits associated with consuming almonds [20], pistachio nuts [21] and walnuts [22] have been extensively investigated. However, studies examining the health effects of consuming hazelnuts are relatively sparse despite the fact that hazelnuts are the second most common nut produced worldwide [23]. In addition, no studies have examined the effects of dry roasted nuts, which are only lightly salted. Lightly salted nuts are now commercially available and provide an alternative to more heavily salted varieties. We hypothesise that this form of nut may be acceptable to consumers and will confer similar health benefits to raw nuts. Therefore, the objective of this randomised crossover study was to compare the effects of consuming a daily 30 g portion of each of whole raw hazelnuts and dry roasted, lightly salted hazelnuts for 28 days on CVD risk factors and acceptance.

**Methods**

**Study design**

This study was conducted using a randomised, crossover design with two treatment periods: raw hazelnuts and dry roasted, lightly salted hazelnuts. During the 2-week run-in period, participants were asked to consume their habitual diet excluding nuts and nut products. Following this, participants were randomly allocated to receive one of the two treatments with the orders balanced. Each treatment period was 4-week duration separated with a 2-week washout period. Participants were asked to continue to consume their habitual diet during the treatment and washout periods. However, they were asked to continue not consuming any nuts or nut products beyond the hazelnuts supplied for the study. Both forms of hazelnuts were packaged into individually portioned, 30-g serving-sized bags. The amount of nuts chosen in this study was based on the National Heart Foundation of New Zealand recommendations [7].

**Participants**

Seventy-two participants were recruited from the general public of Dunedin, New Zealand. Recruitment was through advertisements in the community paper, local newspaper, the University of Otago Staff Bulletin, and the distribution of flyers around the University of Otago campus, Otago Polytechnic campus and local supermarkets. Participants from previous studies within the Human Nutrition Department, who had provided permission to be contacted for participation in future research projects, were also contacted. The inclusion criteria for participation in the intervention were free-living individuals aged 18 years and above. The exclusion criteria were people who: have asthma, allergies or intolerances to nuts, familial or secondary hyperlipidaemia, major chronic disease, or pacemaker or implanted defibrillators; or were current smokers,
pregnant or lactating women, or taking cholesterol-lowering medication or medication known to affect blood lipid concentrations.

The present study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects were approved by the Human Ethics Committee of the University of Otago, New Zealand. Written informed consent was obtained from all subjects. The trial was registered for inclusion in the Australia New Zealand Clinical Trials Registry (ANZCTR) (http://www.anzctr.org.au/), registration code ACTRN12611000838910.

**Nut preparation**

Whole raw, unsalted, Whiteheart hazelnuts were purchased from a nut grower (Uncle Joe’s Walnuts and Hazelnuts, Blenheim, New Zealand). Hazelnuts were shelled and delivered to the researcher 4 weeks before the intervention began for processing and packaging. All nuts used in the study were stored at room temperature in darkness before opening.

To obtain dry roasted, lightly salted hazelnuts, a known quantity of raw hazelnuts were first soaked in a salt–water solution for 30 s and then drained for a further 30 s. One part iodised table salt (Pams, Auckland, New Zealand) to five parts warm, filtered tap water was used to prepare the salt–water solution. The hazelnuts were then spread evenly over oven trays and roasted in a standard preheated oven (Fisher & Paykel, Auckland, New Zealand) at 100 °C for 15 min. Each tray was shaken at 5-min intervals during the roasting process. Upon conclusion of the roasting process, the hazelnuts were removed from the oven and left to cool. Previous research has reported that the nutrient composition of nuts remains largely unchanged when the roasting temperature is below 140 °C [24–27]. The temperatures used for commercial dry roasting of nuts range from 100 to 160 °C. Therefore, our roasting process is comparable to those seen with commercial roasting and is unlikely to substantially change the nutrient composition of the nuts.

To assess the quantity of sodium added to the processed hazelnuts, the nutritional composition of both forms of hazelnuts were analysed on two occasions in four samples (AssureQuality, Auckland, New Zealand). Both hazelnuts had very similar nutrient composition, except for sodium content (Table 1). Raw hazelnuts contained 3.9 mg of sodium per 30 g (13 mg per 100 g), while dry roasted, lightly salted hazelnuts contained 39.9 mg of sodium per 30 g (133 mg per 100 g).

The dry roasted, lightly salted treatment was designed to provide a similar quantity of sodium as commercially available lightly salted nuts, i.e. 145 mg of sodium per 100 g (Mother Earth, Hamilton, New Zealand), and sodium levels below that of commercially salted nuts. On average, commercially available salted nuts (cashew, mixed, peanuts, beer nuts) contain 568 mg of sodium per 100 g (Eta, Manukau City, New Zealand; Homebrand, Auckland, New Zealand; Mother Earth, Hamilton, New Zealand; Signature Range, Auckland, New Zealand).

**Compliance**

Compliance was measured in two ways: by weighing the bags returned at the end of each treatment and by measuring plasma α-tocopherol concentrations. However, it should be noted that plasma α-tocopherol concentrations reflect relatively short-term changes in dietary α-tocopherol [28, 29].

**Dietary assessment**

All participants completed a 3-day diet record (3-DDR), including two weekdays and one weekend day, during the baseline period and during each treatment period (three 3-DDRs in total). Diet records were used to assess participants’ reported nutrient and energy intakes, with food intake recorded at the time of consumption. Participants were provided with electronic scales (Salter Electronic, Salter Housewares Ltd., Kent, UK) to weigh food and attended a 30-min training session by a dietitian outlining how to complete the diet record. The diet records were entered into a computer programme, Diet Cruncher [30], which uses food composition data from the New Zealand Plant and Food Research [31].

**Physical activity**

Physical activity was monitored using New-Lifestyles NL-1000 accelerometers (New-Lifestyles Inc., Lee’s Summit, MO, USA) for seven consecutive days at baseline and

### Table 1 Energy and nutrient composition of hazelnuts used in the study

<table>
<thead>
<tr>
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<th>Raw hazelnuts (30 g)</th>
<th>Dry roasted, lightly salted hazelnuts (30 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kJ)</td>
<td>846</td>
<td>846</td>
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<tr>
<td>Protein (g)</td>
<td>4.7</td>
<td>4.6</td>
</tr>
<tr>
<td>Fat (g)</td>
<td>18.5</td>
<td>18.4</td>
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<tr>
<td>Saturated fat (g)</td>
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<td>1.3</td>
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<tr>
<td>Monounsaturated fat (g)</td>
<td>14.6</td>
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<tr>
<td>Polyunsaturated fat (g)</td>
<td>2.6</td>
<td>2.9</td>
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<tr>
<td>Carbohydrate (g)</td>
<td>4.7</td>
<td>5.2</td>
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<tr>
<td>Sodium (mg)</td>
<td>3.9</td>
<td>39.9</td>
</tr>
<tr>
<td>α-Tocopherol (mg)</td>
<td>5</td>
<td>4.3</td>
</tr>
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</table>
during each treatment period (three sets of measurements in total). The daily and 7-day average number of steps and distance were recorded from the accelerometers after they were returned by each participant.

Biochemical analysis

Two fasting blood samples were collected from each participant, following a 12-h overnight fast, during the clinic visits before and after each treatment period (eight samples in total). An experienced nurse collected two blood samples on non-consecutive days in one 10 mL Vacutainer containing dipotassium EDTA for analysis of plasma lipids, apolipoproteins and α-tocopherol, and one 5 mL Vacutainer containing fluoride and oxalate for the analysis of plasma glucose (Belton Dickinson Diagnostics, Franklin Lakes, NJ, USA). Vacutainers were inverted and stored in a chilly bin containing frozen ice-pads after blood samples were drawn. All blood samples were separated by centrifugation at 3000g, for 15 min at 4 °C within 3 h of being drawn. Plasma aliquots were stored in Eppendorf tubes at −80 °C until analysis.

Plasma total cholesterol, high-density lipoprotein (HDL)-cholesterol and triacylglycerol (TAG) concentrations were measured in all blood samples by enzymatic methods using kits and calibrators supplied by Roche Diagnostics (Mannheim, Germany) on a Cobas Mira Plus Analyst. HDL-cholesterol was measured using the supernatant following the precipitation of apolipoprotein B containing lipoproteins with phosphotungstate–magnesium chloride solution [32]. Plasma low-density lipoprotein (LDL)-cholesterol concentrations were calculated using the Friedwald formula [33]. Plasma apolipoprotein A1, B100, and glucose concentrations were determined by using commercial kits from Roche Diagnostics (Mannheim, Germany) on a Cobas Mira Plus Analyst. Plasma glucose was measured using the hexokinase method as described by Neeley [34]. Plasma α-tocopherol was measured using the Agilent high-performance liquid chromatography system (1100 series, Agilent Technologies Inc., Santa Clara, CA, USA) based on methods described by Thurnham et al. [35].

Calibration and quality control were maintained by participation in the Royal Australasian College of Pathologists Quality Assurance Programme. The inter-assay coefficient of variation for each outcome measurement was total cholesterol: 3.31 %, HDL-cholesterol: 5.82 %, TAG: 4.31 %, apolipoprotein A1: 3.35 %, apolipoprotein B100: 2.71 %, glucose: 3.22 % and α-tocopherol: 2.81 %.

Blood pressure

At each clinic visit, blood pressure was measured in triplicate and the mean was recorded, using an Omron blood pressure monitor (Model HEM-907, Kyoto, Japan). Participants were seated for approximately 5 min before blood pressure was measured.

Anthropometric measurements

Height was measured at baseline using standard procedures to the nearest millimetre using a stadiometer. Participants stood on the stadiometer, with heels against the backboard. The head block was lowered to rest on the top of the head. Participants were asked to take a deep breath before the height measurement was taken. Body weight and body composition were assessed before and after each treatment period, in the same visit in which blood samples were collected. Participants were barefoot and wore light clothing for these measurements. Body weight and body composition were measured using a bioelectrical impedance analyser (Tanita, Model TFB-310, Tokyo, Japan).

Acceptance for nuts

"Overall liking” at the pre- and post-exposure tasting session

The pre- and post-exposure tasting sessions were held in the sensory laboratory, Department of Food Science, University of Otago. The pre-exposure tasting session was held at the end of the 2-week baseline period, while the post-exposure session was held immediately upon the conclusion of the study. At the pre-exposure tasting session, participants were given a detailed briefing on the nature of the study and the importance of complying with the instructions. Both taste testing sessions involved a 20-min product assessment acceptability test. Participants were seated in individual sensory booths and presented with eight food items, water at room temperature and a recording ballot. The food items were selected based on their fat, sodium and sugar contents. The food items included the raw hazelnuts and the dry roasted, lightly salted hazelnuts used in the intervention, short bread (high-fat, sweet), peanuts (high-fat, salty), chocolate (medium-fat, sweet), potato crisps (medium-fat, salty), raisins (low-fat, sweet) and rice crackers (low-fat, salty). Before starting the taste testing and between each sample, participants were asked to rinse their mouths with water. Participants were instructed both visually and verbally how to rate their “overall liking” on a 150-mm visual analogue scale (VAS) anchored with “Dislike extremely” on the left-hand side (0 mm), “Neither like nor dislike” in the middle (75 mm) and “Like extremely” on the right-hand side of the scale (150 mm). Participants were asked to wait for at least 1 min between each sample and asked not to converse during testing.
“Desire to consume” and “overall liking” during the intervention

Throughout each 4-week treatment phase, participants were asked to complete the exposure ballots at the time of consuming the daily 30 g allowance of hazelnuts. Participants were able to consume the daily portion of hazelnuts, as and when desired, providing the daily allowance was not shared with others. Nuts were available for family and friends upon the conclusion of the study. At the time of consuming the hazelnuts, participants were asked to record the time of day when and the location where the nuts were consumed. They were then asked to eat one hazelnut and rate their “Desire to consume” on a 150-mm VAS anchored with “Strong desire not to consume” on the left-hand side (0 mm) and “Strong desire to consume” on the right-hand side of the scale (150 mm). Next, participants were asked to consume the rest of their daily allowance of hazelnuts and rate their “overall liking” using the same 150-mm VAS that was used in the laboratory-based tasting sessions.

Statistical analysis

In order to have 80 % power to detect at the 2-sided 0.05 level, a difference of 0.25 mmol/L in LDL-cholesterol between groups, assuming a standard deviation of 0.65 mmol/L and a correlation between baseline and follow-up values of 0.5 or higher but without making any assumptions about the correlations between treatment effects for the same participant, 80 participants would be required to provide full data.

The primary analyses were to compare the effect of consuming two different forms of hazelnuts on biochemical indices (plasma total, LDL- and HDL-cholesterol, TAG, apolipoprotein A1 and B100, and α-tocopherol), dietary data (energy, total fat, saturated fat, monounsaturated fat, polyunsaturated fat, protein, carbohydrate, alcohol, cholesterol, dietary fibre and vitamin E), physical activity (steps and distance), blood pressure, body weight and composition (body weight, BMI, fat mass, fat-free mass, percentage body fat) and acceptability data (“desire to consume” and “overall liking” ratings). Linear mixed models, with a random participant effect to account for the repeated measures, were used to examine the between-groups effects of the two different forms of hazelnuts on the continuous outcomes. These models included terms for baseline values so that comparisons between the forms of hazelnuts were in terms of differences in changes and the intervention period (first or second) to adjust for any influence of this on outcomes. Interactions between nut type and the intervention period were investigated to ensure there was no evidence for carryover effects. Log transformations were used for both final and baseline values of dependent variables where this improved residual normality and/or homoscedasticity. Paired t tests were then used to explore within-group changes for nutrient intakes, physical activity, biochemical indices, blood pressure, body composition and acceptance before and after each 4-week intervention to assist interpretation of between-groups effects and as within-group effects of interest in themselves. Similarly, linear mixed models were used to compare ratings of “desire to consume” and “overall liking” between the two forms of hazelnuts with random participant and participant-nut form effects. The association between ratings of “desire to consume” and “overall liking” was assessed using the Pearson’s correlation coefficient.

All analyses were based on modified intention to treat principles (using all available data for each analysis) and were conducted using Stata 11.1 (StataCorp, College Station, TX, USA). All tests were two-sided with the level of statistical significance set at 5 %. In some cases, non-significant tendencies (0.05 ≤ P < 0.10) are highlighted.

Results

Participant characteristics

Seventy-eight subjects were initially recruited and screened to participate in the study. Five participants withdrew prior to the collection of baseline measurements and randomisation due to commitments unrelated to the study, and one participant was later discovered to have diabetes and was retrospectively excluded as not meeting the inclusion criteria. The remaining 72 participants completed the study, which consisted of 48 females and 24 males. The mean (SD) age was 45.5 (14.8) years, and the mean (SD) BMI was 26.7 (4.69) kg/m².

Compliance

Compliance by weighing the returned bags was high and similar for both forms of hazelnut: 98.4 % of raw hazelnuts and 98.1 % of dry roasted, lightly salted hazelnuts were consumed using this method. An objective measure of compliance through the assessment of plasma α-tocopherol concentrations was also used. Plasma α-tocopherol concentrations increased significantly following the raw hazelnut-enriched diet (P = 0.008), with a tendency for the dry roasted, lightly salted hazelnut-enriched diet (P = 0.099), supporting the high compliance rate observed by the aforementioned methods.

Dietary data

Seventy-one of the 72 study participants completed a 3-DDR at baseline and during the two treatment phases.
Nutrient intakes at baseline and at the end of each treatment phase are summarised in Table 2. The only significant differences between the two treatments were polyunsaturated fat (P = 0.027), dietary fibre (P = 0.036) and sodium (P = 0.032) intakes. The reported grams of polyunsaturated fat and dietary fibre consumed were significantly higher when consuming raw hazelnuts compared to dry roasted, lightly salted hazelnuts. On the other hand, the sodium intake when consuming raw hazelnuts was significantly higher compared to the dry roasted, lightly salted hazelnuts (2764 vs. 2534 mg, respectively). When compared to baseline, energy derived from total fat and monounsaturated fat, as well as vitamin E intake was significantly higher, while energy from carbohydrate was significantly lower when the diets were supplemented with hazelnuts (all P < 0.001).

**Clinical outcomes**

The clinical outcomes at baseline and at the end of each treatment phase are summarised in Table 3. There was no evidence of a difference in total cholesterol, LDL-cholesterol, apolipoproteins, glucose and α-tocopherol concentrations, systolic blood pressure, body composition, and physical activity level between the two forms of hazelnuts (all P ≥ 0.125). However, HDL-cholesterol (1.45 vs. 1.41 mmol/L; P = 0.037) and TAG (1.12 vs. 1.03 mmol/L; P < 0.001) concentrations were significantly higher following the raw hazelnuts compared to the dry roasted, lightly salted treatment. In addition, there was a non-significant tendency for higher diastolic blood pressure following the consumption of raw hazelnuts compared with dry roasted lightly salted hazelnuts (72.6 vs. 71.5 mmHg; P = 0.054).

Compared with baseline, the values at the end of both hazelnut interventions were significantly reduced for total-C/HDL-C ratio (both P < 0.001) and systolic blood pressure (both P ≤ 0.034). On the other hand, HDL-cholesterol (both P < 0.001) and apolipoprotein A1 (both P ≤ 0.005) concentrations increased significantly from baseline as a result of hazelnut consumption. In addition, compared to baseline, plasma α-tocopherol concentration was higher when the diet was supplemented with raw hazelnuts (P = 0.008) with a tendency for higher concentrations for the dry roasted, light salted hazelnuts (P = 0.099). The change in body weight from baseline to the end of hazelnut interventions was close to zero (−0.03 to −0.13 kg).
Hazelnut consumption also had no significant effect on fat mass, fat-free mass and total body water.

Acceptability for nuts

The “desire to consume” (Fig. 1a) and “overall liking” (Fig. 1b) ratings for both forms of hazelnuts were high, i.e. ≥105 mm on the 150-mm VAS. Mean “desire to consume” ratings for the dry roasted, lightly salted hazelnuts were not statistically significantly different from the ratings for raw hazelnuts (P = 0.418). Mean “overall liking” ratings for the raw and dry roasted lightly salted hazelnuts over the 28-day exposure period followed the same pattern as the “desire to consume” ratings, in which no significant difference in “overall liking” ratings was found between the two forms of hazelnuts (P = 0.205). Ratings for “desire to consume” and “overall liking” remained unchanged throughout the 28-day exposure period. “Desire to consume” and “overall liking” ratings for both forms of hazelnuts were positively correlated (both P < 0.001; data not shown). In addition, consuming hazelnuts for 28 days each had no significant effect on “overall liking” ratings from pre (raw 105 mm; dry roasted, lightly salted 110 mm)- to post-exposure (raw 108 mm; dry roasted, lightly salted 111 mm) taste testing sessions.

Discussion

The present study is to the best of our knowledge the first to compare the effects of consuming processed hazelnuts (dry roasted, lightly salted) and raw hazelnuts on cardiovascular risk factors and acceptance. Our results showed minimal differences in clinical outcomes between the two forms of hazelnuts. The incorporation of raw or dry roasted, lightly salted hazelnuts into the usual diet was associated with lower total-C/HDL-cholesterol ratio and systolic blood pressure and increased HDL-cholesterol and apolipoprotein...
A1 concentration, without adverse changes in body weight or acceptance.

Three previous studies have investigated the effect of consuming processed almonds (raw, roasted salted, roasted butter) and peanuts (raw, roasted unsalted, roasted salted, honey roasted, butter or spiced), on blood lipids and lipoproteins at intakes greater than this study (42–100 g) [12–14]. All studies showed no significant differences in change in blood lipid profiles between different forms of nuts. However, unlike previous work, the change in HDL-cholesterol and TAG concentrations was statistically significantly different between forms of hazelnuts in the present study. HDL-cholesterol and TAG concentrations were significantly higher following the consumption of the raw hazelnuts, when compared to the dry roasted, lightly salted hazelnuts. Dietary components and physical activity level have the potential to affect HDL-cholesterol and TAG concentrations. For instance, high intakes of free sugar may be associated with elevated TAG concentrations [36]. In addition, high alcohol and saturated fat consumption may increase HDL-cholesterol, whereas polyunsaturated fat may reduce HDL-cholesterol concentrations [37]. Intakes of these dietary components were not significantly different between the two hazelnut interventions, with only polyunsaturated fat intakes being slightly higher during the period where raw hazelnuts were consumed. Exercise levels as measured by accelerometer were also similar between the two groups. Thus, it is unclear why this difference has occurred.

The present study found no significant differences in the changes in apolipoprotein A1 and apolipoprotein B100 concentrations between raw and dry roasted, lightly salted hazelnuts. No previous research investigating the effect of consuming processed nuts on apolipoprotein concentrations was identified. The present study would suggest that consuming raw nuts or dry roasted, lightly salted nuts has a similar influence on plasma apolipoprotein concentrations. In addition, the current study found that compared with baseline, the apolipoprotein A1 concentration at the end of both hazelnut interventions was significantly higher. The increase in apolipoprotein A1 seen in the present study reflects the increase in HDL-cholesterol. It is encouraging to see both these indices increase with hazelnut consumption.
Several recent studies have compared the effects of the digestibility of raw and roasted nuts [38–41]. Overall, these studies suggest that although roasting results in a higher proportion of small particles following mastication, this has a negligible effect on digestion kinetics, lipid release and the bioaccessibility of bioactives. This may in part explain the lack of difference between the raw and roasted hazelnut treatments for the majority of lipoprotein parameters measured in this study, as well as body weight.

Spiller et al. [14] and Jones et al. [12] reported no statistically significant difference in systolic and diastolic blood pressure between different forms of nuts. The present study found that although compared with baseline both forms of hazelnuts significantly reduced systolic blood pressure, only the dry roasted, lightly salted hazelnut treatment showed a significant reduction in diastolic blood pressure. The dry roasted, lightly salted hazelnuts showed a tendency for a greater reduction in diastolic blood pressure when compared to the raw hazelnuts. This suggestive finding was also reported in a recent meta-analysis [42]. It should be noted that the nuts commercially available in New Zealand contained around 570 mg of sodium per 100 g. The sodium content of the salted nut variety used in the current study, Spiller et al.’s [14] and Jones et al.’s [12] contained 133, 210 and 679 mg per 100 g of nuts, respectively. In the aforementioned studies, participants were provided with 30, 100 and 42 g of nuts, respectively, equating to 40, 210 and 285 mg of sodium per day. This is equivalent to 1.7, 9.1 and 12.4 % of the recommended upper limit for sodium of 2300 mg/day [43]. It appears that when the contribution of sodium from nuts is ≤285 mg/day, there is no adverse effect on blood pressure. Future studies should investigate whether long-term consumption of large quantities of commercially available nuts, with a sodium content of more than four times that used in the present study, would have a negative impact on blood pressure.

Previous work has shown that roasting hazelnuts reduces the vitamin E content by up to 10–38 % [25, 27]. Our analysis indicated that the roasting process reduced the vitamin E content by around 15 %. However, this reduction did not influence plasma α-tocopherol concentrations. The present study found no significant difference in plasma α-tocopherol concentrations between the raw and dry roasted, lightly salted hazelnuts treatments. Consuming raw or dry roasted, lightly salted hazelnuts both improved plasma α-tocopherol concentration, although the change from baseline was only statistically significant for the raw hazelnut treatment. Whether this result can be extended to commercially batch roasted nuts is unknown, particularly as the hazelnuts used in the current study were dry roasted at a low temperature for a short duration. Results from the present study are in agreement with previous research, which showed no significant difference in plasma α-tocopherol concentrations between ground, sliced and whole hazelnuts, and the consumption of all forms of hazelnuts significantly increased plasma α-tocopherol [44]. Thus, hazelnuts appear to be a rich source of vitamin E. This is of particular importance, given that epidemiological research has shown an inverse association between vitamin E intake from nuts and seeds and overall risk of CHD [45].

Previous research with weaker study designs (e.g. single or sequential arms) and conducted using small (n ≤ 30) samples (and so at risk of being underpowered for small but still clinically important differences) found no evidence for changes in plasma glucose concentrations following hazelnut consumption [46–48]. One recent randomised parallel study reported no significant difference in blood glucose between four different flavoured forms of peanuts in 151 participants [12]. The current study, which has used a randomised crossover design with a larger sample size (n = 72), provides more convincing evidence that hazelnut consumption has no influence on glycaemic control in non-diabetic individuals. These findings are in agreement with results from two recent reviews which reported no beneficial relationship between nut consumption and glycaemic control [49, 50].

Nuts are high in energy and fat and thus have the potential to contribute to a positive energy balance [51]. As the rates of overweight and obesity have increased both in New Zealand and internationally [52], questions surrounding recommendations to increase nut consumption have subsequently arisen. The predicted weight gain over 4 weeks based only on the additional energy provided by hazelnuts and assuming no dietary compensation would be 0.71 kg [53]. This predicted weight gain is likely to be overestimated even without dietary compensation because the dynamic nature of metabolism as a result of weight change was not considered [54]. However, no evidence for weight gain was observed with the consumption of either raw or dry roasted, lightly salted hazelnuts in the present study, and in fact, small reductions in weight were observed. Results of the present study further add to previous research, which suggests that regular nut consumption results in either no weight gain or less weight gain than predicted [55–59]. This may be explained by dietary compensation, inefficient energy absorption, and an increase in metabolic rate [51, 60].

The present study shows that although both forms of hazelnuts increased polyunsaturated fat intake and lowered sodium intake, the magnitude of the change was significantly different between the treatments. The absolute amount of polyunsaturated fat was significantly higher during the raw hazelnut period, while the sodium intake was significantly lower during the dry roasted lightly salted hazelnut period. It is important to note that the sodium from the dry roasted lightly salted hazelnuts only contributed
<2 % (40/2534 mg) of the total sodium intake during the intervention. There are several possible explanations for this. Firstly, participants may have reduced the intake of other savoury foods that are high in sodium from their diet when they consumed dry roasted, lightly salted hazelnuts. Secondly, accurate measurement of dietary sodium is challenging. Therefore, this could be a spurious finding and should be interpreted with caution. Overall, the addition of 30 g of either form of hazelnuts to the diet significantly increased the percentage of energy derived from monounsaturated fat, while the percentage of energy derived from carbohydrate and sugar intake were significantly lowered during the hazelnut-enriched diets. Furthermore, one 30 g serving of hazelnuts provided approximately 50 % of the adequate intake of vitamin E for males and approximately 65 % of the adequate intake for females [43]. Thus, incorporating nuts into the usual diet could be an effective way to meet the recommended intake for vitamin E [61]. When the dietary data are taken together, it appears that the addition of a 30-g portion of either raw or dry roasted, lightly salted hazelnuts to a typical New Zealand diet significantly improves overall diet quality and should therefore be encouraged as part of a cardioprotective diet.

Two relatively small studies (n < 40) reported that honey roasted and roasted, salted nuts have higher palatability ratings compared to raw nuts when tested on a single session [8, 9]. To exert health effects, nuts must be consumed regularly, and in sufficient quantity. Prolonged exposure to a food may influence palatability ratings. Therefore, these one-off ratings provide limited information. Seven clinical studies have investigated the effects of regular nut consumption on acceptance. Two relatively small studies (n < 24 per treatment) assessed acceptability at pre- and post-exposure [13, 55], while a further five studies measured acceptability daily throughout the exposure period [19] and at pre- and post-exposure [15–18]. Jones et al., which was the only study that has compared the acceptability of flavoured nuts, found a small but significant decline (<15 %) in acceptance ratings for four flavour forms (salted, unsalted, honey roasted and spiced) of peanuts after 12 weeks of exposure. However, the authors did not report the between-groups results [19]. The current study is the first we are aware of to compare the acceptability of regularly consuming raw and processed hazelnuts on a daily basis during the exposure period. Results showed that raw hazelnuts appear to be as acceptable as dry roasted, lightly salted hazelnuts and consuming both forms of hazelnuts at recommended amount (i.e. 30 g) for 28 days each does not influence participants’ acceptance. Despite the differences in study design and sample size, the present results are consistent with the previous long-term studies, where repeated consumption of nuts appears to have minimal influence on acceptance.

Conclusion

To conclude, both raw and dry roasted, lightly salted hazelnuts were highly acceptable and improved CVD risk factors to a similar extent; thus, current recommendations to consume nuts regularly can be extended to include dry roasted, lightly salted hazelnuts. This would provide consumers with increased choice, which may enhance the likelihood of consuming sufficient nuts as part of the cardioprotective diet, especially in populations such as New Zealand adults where nut consumption levels are much lower than recommendations.

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Compliance with ethical standards

Conflict of interest None of the authors had any personal or financial conflict of interest.

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