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Cooking parameters affect the sodium content of prepared pasta

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ABSTRACT

The quantitative effect of different preparation variables on the sodium content of cooked dry pasta was evaluated. Semolina spaghetti (< 5 mg sodium/100 g) was cooked by a typical method (454 g, 5.68 L water, 36 g salt, al dente, no rinsing) and after systematic variation of amount of salt, water:pasta ratio, cooking volume and time, rinsing, pasta shape, whole grain. Sodium was assayed by ICP-MS, including rigorous quality control. Pasta cooked without salt had < 5 mg sodium/140 g serving, and 247–490 mg/serving when cooked in salted water by the different variations. Rinsing reduced sodium by 34%. There was a linear relationship between salt concentration in cooking water and sodium in cooked pasta; doubling the concentration increased sodium by 243 mg/serving (> 10% of 2300 mg/day), relative to the reference method. No other variables affected sodium. Results allow more accurate estimation of sodium intake from cooked pasta, since food composition tables that do not reflect variations in cooking parameters.

1. Introduction

High sodium intake can have serious health repercussions, including increased risk of hypertension and cardiovascular disease (Mozaffarian, 2016). Cardiovascular disease (CVD) is responsible for approximately 801,000 deaths each year in the U.S. and is the leading cause of death for both men and women (Mozaffarian et al., 2016). Hypertension, defined as blood pressure ≥140 systolic and ≥90 diastolic, has an estimated prevalence of 29% of the adult population based on the 2009–2012 National Health and Nutrition Examination Survey (Jackson, King, Zhao, & Cogswell, 2016). Reducing dietary sodium can improve blood pressure (Cook, Appel, & Whelton, 2016; He & MacGregor, 2002; Strazzullo, D'Elia, Kandala, & Cappuccio, 2009; Vollmer et al., 2001). The Adequate Intake (AI) for sodium for young adults is 1500 mg/d and for older adults (50–70 years old) is 1300 mg/day (Institute of Medicine, 2006), and the American Heart Association Diet and Lifestyle Recommendations, revised in 2006 (Lichtenstein et al., 2006), include limiting sodium intake to 2300 mg/day [equivalent to 6 g salt (~1 tsp)]. The Daily Value for sodium used on food labels in the U.S. is 2300 mg (U.S. Department of Health and Human Services, 2007). However, individuals within the U.S. and other industrialized countries consume 6–12 g of salt per day (Brown, Tzoulaki, Candeias, & Elliott, 2009; Moshfegh et al., 2012).

The predominant sources of dietary sodium include processed foods and salt added during meal preparation and at the table (Anderson et al., 2010; Brown et al., 2009; Moshfegh et al., 2012; Quader et al., 2017; World Health Organisation, 2012). While most natural food sources, including unprocessed fruits and vegetables, meats, dairy products, grains, and legumes are low in sodium (US Department of Agriculture, 2016; World Health Organisation, 2012), the sodium content of these foods increases significantly when salt is added during processing, cooking, preparation, and at the table (Moshfegh et al., 2012). The What We Eat In America (WWEA) National Health and Nutrition Examination Survey (NHANES) has estimated that 11% of sodium intake is from discretionary use of salt during home cooking and at the table (Sebastian, Wilkinson Enns, Steinfeldt, Goldman, & Moshfegh, 2013).

Pasta is a food to which salt is often added during preparation, and it is in the top 12 foods contributing to sodium intake in the home (Quader et al., 2017). In the NHANES, 40% of respondents indicated they use salt "very often" in cooking, with pasta being one of the top five foods to which salt is added in home meal preparation (Sebastian

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Table 1
Some culinary recommendations for cooking dry semolina spaghetti, methods used to cook pasta analyzed for the USDA National Nutrient Database for Standard Reference (US Department of Agriculture, 2016), and package instructions from different brands.

Source	Amount of Pasta and Water		Salt		Boiling time/ Firmness	Rinsing
	Volume water/ weight pasta[a]	Calculated mL water/g pasta	Specified	Calculated g salt/L water[b]		
Culinary methods:						
McGee (2009)	4–6 qt/lb	8.3–12.5	not specified	n/a	not specified	not specified
Smithonian.com (Esposito, 2013)	4–5 qt/1 lb	8.3–10.4	1 Tbsp/qt	19	al dente	no
International Pasta Organisation (Organisation, 2016)	1 L/100 g	10.0	2 tsp/qt	12.7	al dente	not specified
The Food Network ("The Food Network. How to cook Italian pasta: A step by step guide," 2014)	6 qt/1 lb	12.5	0.5 Tbsp qt	9.5	al dente	not specified
Jenkins (Jenkins, 1997)	≥5 qt/1lb	≥ 10.4	2 Tbsp/5qt	7.6	al dente	no
Joy of Cooking (Rombauer, Rombauer Becker, & Becker, 2006)	6 qt/1 lb	12.5	1 Tbsp/3 qt	6.3	al dente	no
The Best Recipe ("Editors of Cook's Illustrated. *The Best Recipe*. Revised Edition," 2004)	≥4 qt/lb	≥8.3	1 Tbsp/4 qt	4.8	al dente	no
USDA National Nutrient Database for Standard Reference ("USDA National Nutrient Database for Standard Reference. Release 28," 2016):						
Pasta cooked without salt[c]	3.7–5.5 qt/1.3–1.8 lb	4.3–8.4	none	0	10–14 min	no
Pasta cooked with salt[d]	3.7–5.5qt/1.3–1.8 lb	4.3–8.4	0.19–0.36 Tbsp/qt	3.6–6.8	10–14 min	no
Package instructions for different brands[e,f]:						
Barilla® [f]	4–6 qt/1 lb	8.3–12.5	to taste	varies	9 min (al dente)	no
Mueller's	4 qt/1 lb	8.3	to taste	varies	10–11 min	no
San Giorgio	5 qt/1 lb	10.4	1 Tbsp/5 qt	3.8	9 min (al dente)	no
Ronzoni®: 1 serving	2 qt/0.25 lb	16.7	1 tsp/2 qt	3.2	10 min (al dente)	no
2 servings	3 qt/0.5 lb	12.5	2 tsp/3 qt	4.2	10 min (al dente)	no
4 servings	5 qt/1 lb	10.4	1 Tbsp/5 qt	3.8	10 min (al dente)	no
Pastifico G. DiMarlino	5 L/500 g	10.0	"slightly salted"	Varies	8 min	no

[a] 1 lb = 454 g; 1 qt = 0.946 L.
[b] 18 g per tablespoon (Tbsp), 6 g per teaspoon (tsp), per USDA National Nutrient Database for Standard Reference (US Department of Agriculture, 2016).
[c] NDB number 20121, "Pasta, cooked, enriched, without added salt" (US Department of Agriculture, 2016).
[d] NDB number 20,321 "Pasta, cooked, enriched, with added salt" (various brands, cooked according to package instructions) (US Department of Agriculture, 2016).
[e] Semolina spaghetti. Package instructions obtained 14 May 2017.
[f] Used for this study.

et al., 2013). The estimated annual per capita pasta consumption in the US is approximately 8.8 kg (19.36 lb) (International Pasta Organisation, 2013). Pasta is a broad food category that generally describes an unleavened dough containing milled durum wheat and water that is extruded in sheets and cut to make noodles and a myriad of other shapes (Potter & Hotchkis, 1998). Wheat that is milled such that the particles are coarse is referred to as semolina. To create a shelf stable product, the extruded dough is oven dried to specific moisture content of 12% (Potter & Hotchkis, 1998), and the dried pasta is prepared for consumption by cooking in boiling water. Recommended cooking parameters for dry pasta vary widely within the culinary community and among manufacturers, with varying water to pasta ratios and amount of salt added to the cooking water, as illustrated by the examples in Table 1.

The sodium content of packaged dry pasta is minimal [< 2 mg per 57 g (2 oz.) portion], but the addition of salt during cooking can result in a substantial increase. The mean value in the USDA National Nutrient Database for Standard Reference (SR) for sodium in pasta cooked with salt is 131 mg/100 g (183 g per 140 g standard serving) (US Department of Agriculture, 2016). There are limited reports on sodium in pasta cooked with different amounts of salt and none on quantitative uptake with home cooking conditions and varying pasta type, water to pasta ratio, amount of salt in the cooking water, and other factors that might differ within recommended and customary practices (Albrecht, Asp, & Buzzard, 1987; Antonelli & Colwell, 2006). Quantifying the impact of different cooking parameters would help guide the consumer to practices with concrete impact on dietary sodium, as well as allow researchers to estimate sodium in cooked pasta consumed by a given population or individual based on cooking methods used, given that the value in SR is an average. Studies relating different cooking parameters to sodium in cooked pasta are limited. In one report, deionized water was used, without added salt, to assess sodium retention, not uptake (Albrecht et al., 1987). In another investigation (Albrecht et al., 1987), different types of pasta were evaluated (macaroni, egg noodles, spaghetti), but the amounts were small [38–71 g (1.3–2.5 oz)] and the water to pasta ratio and amount of salt varied between pasta types, so that sodium in the cooked pasta could not be related to particular cooking parameters. In another study (Antonelli & Colwell, 2006), pasta (semolina spaghetti and penne, whole wheat spaghetti, and white rice based pasta) was cooked with and without salt. However, cooking was done on a commercial food service scale, many details about the cooking method were not included, parameters other than the amount of salt were not varied, and only two levels of salt were tested. Thus, it was not possible to establish how different parameters affected the sodium content of pasta, or pasta cooked on a home preparation scale.

The objective of this study was to quantify the effect of different variables, including the amount of salt added to the cooking water, the water to pasta ratio, rinsing the pasta after cooking, different pasta shapes, and whole grain pasta, on the sodium content of pasta cooked on a home preparation scale, and to provide results in a manner that can be utilized by health care and public health professionals to educate consumers on dietary sodium.

2. Materials and methods

2.1. Experimental design

A typical consumer-scale cooking procedure for semolina spaghetti was chosen as the "reference method": 454 g pasta (1 lb), 5.68 L (6 qt) boiling water (12.5 mL/g water to pasta ratio), 36 g (2 Tbsp) table salt

Table 2
Experimental treatments with cooking parameters varied systematically relative to a reference method (Treatment A).

Treatment[a]	Variable	Pasta (g)[b]	Salt (NaCl) (g)[c]	Water (mL)	Pasta Shape	Doneness (Cooking Time)[c]	Flour Type	Salt concentration in cooking water (g/L)	Water: Pasta Ratio (mL/g)
A	Reference method	454	36	5678	Spaghetti	al dente (9 min)	Semolina	6.34	12.5
B	Salt Amount, Low	454	18	5678	Spaghetti	al dente (9 min)	Semolina	3.17	12.5
C	Cooking volume and salt concentration	227	9	2839	Spaghetti	al dente (9 min)	Semolina	3.17	12.5
D	Pasta Shape	454	36	5678	Elbow macaroni	al dente (9 min)	Semolina	6.34	12.5
E	Cooking Time	454	36	5678	Spaghetti	Soft (11 min)	Semolina	6.34	12.5
F	Flour Type	454	36	5678	Spaghetti	al dente (7 min)	Whole Grain	6.34	12.5
G	No salt	454	0	5678	Spaghetti	al dente (9 min)	Semolina	0	12.5
H	Rinsing[d]	454	36	5678	Spaghetti	al dente (9 min)	Semolina	6.34	12.5
I	Salt Amount, Moderate	454	54	5678	Spaghetti	al dente (9 min)	Semolina	9.51	12.5
J	Salt Amount, High	454	72	5678	Spaghetti	al dente (9 min)	Semolina	12.7	12.5
K	Water to Pasta Ratio, Higher	227	36	5678	Spaghetti	al dente (9 min)	Semolina	6.34	25.0
L	Pasta Shape	454	36	5678	Angel hair pasta	al dente (4 min)	Semolina	6.34	12.5
M	Water to Pasta Ratio, Lower	1032	36	5678	Spaghetti	al dente (9 min)	Semolina	6.34	5.5

[a] Cooking time started as soon as the pasta was added to the pot of boiling water, cooked uncovered with moderate stirring. Pasta was then drained in a stainless steel colander for one minute, without agitation or rinsing, except Treatment H, as indicated.
[b] Weight ± 0.5 g, using only whole pieces of pasta.
[c] 18 g per tablespoon (6 g per teaspoon) per USDA National Nutrient Database for Standard Reference (US Department of Agriculture, 2016).
[d] Pasta was cooked and then rinsed after initial draining for one minute, using 2.839 L of cool tap water and then allowing to drain an additional minute.

(NaCl) [6.34 g/L (1 tsp/qt)], and no rinsing after cooking. Parameters were then varied one by one in a series of treatments (summarized in Table 2), with the following rationale: *Amount of salt added to cooking water:* Instead of 36 g (2 tbsp), amounts of 0, 18, 54, and 72 g were tested, with the hypothesis that there will be a linear relationship between amount of sodium added and sodium content of the cooked pasta (Treatments G, B, I, and J respectively). *Cooking volume and amount of salt:* Instead of 5.68 L (6 qt) of water, half the amount of pasta was boiled in 2.84 L (3 qt) of water, with one fourth the amount of salt (Treatment C) (same sodium concentration as in Treatment B). *Pasta shape:* Elbow macaroni and angel hair pasta were chosen to the test effect of pasta shape on sodium uptake, with the hypothesis that sodium content will differ between pasta shapes due to surface area differences (Treatments D and L). Along with regular spaghetti, these shapes are the most commonly consumed in the U.S. [proprietary data obtained by U.S. Nutrient Data Laboratory (Beltsville, MD, USA) from Nielsen, 2012 (http://www.nielsen.com/us/en.html)]. *Cooking time:* Pasta was cooked until soft versus the al dente standard, with the hypothesis that longer cooking time and softer noodle will increase sodium uptake (Treatment E). *Type of flour:* Whole grain spaghetti was chosen as the most popular whole grain alternative to semolina pasta in the U.S. based on point of sales data [proprietary data obtained by U.S. Nutrient Data Laboratory (Beltsville, MD, USA) from Nielsen, 2012 (http://www.nielsen.com/us/en.html)], with the hypothesis that sodium uptake will differ for whole grain versus semolina (Treatment F). *Rinsing:* Pasta was rinsed after cooking, with the hypothesis that rinsing would decrease the sodium content (Treatment H). *Amount of pasta (water to pasta ratio):* Half the amount of pasta (25.0 mL/g water to pasta ratio) and 2.3 times the amount of pasta (5.5 mL/g, chosen to match the ratio in the commercial food service scale study reported by Antonelli and Colwell (2006)), were cooked with the same volume of water and salt concentration, with the hypothesis that sodium uptake will not differ based on the water to pasta ratio (Treatments K and M).

Each treatment was performed in three replicate experiments. Sodium in the dry and cooked pasta from each experiment was analyzed in triplicate. Moisture was measured in each composite by vacuum drying to a constant weight at 635 mm Hg and 65–70 °C (Association of Official Analytical Chemists, 2003), to document the dry matter content.

2.2. Pasta

Two packages of pasta (total of ~1–1.5 kg) of the same brand (Barilla®) and lot number were purchased from a local retail market (Blacksburg, VA) and used for each replicate of each treatment (Table 2): 454 g (1 lb) boxes enriched semolina spaghetti for Treatments A, B, C, E, G, H, I, J; 454 g (1 lb) boxes enriched semolina elbow macaroni for treatment D; 375 g (13.25 oz) boxes whole grain spaghetti for Treatment F; 454 g (1 lb) boxes enriched semolina angel hair pasta for Treatment L. Iodized table salt (Morton®) from two 737 g boxes was used for experiments with added salt.

2.3. Preparation of pasta

For each experiment, approximately half of each box of pasta was included in each of the cooked and uncooked composites. The uncooked composites consisted of 100–200 ± 0.5 g from each box.

Tap water in the volume specified (Table 2) ± 0.1 mL was added to a 9.46 L (10 qt.) stainless steel pot, for all but Treatment C [3.79 L (4 qt.) pot]. The specified amount of salt (Table 2) (± 0.005 g) was added, and the water was brought to a rolling boil on the stovetop (electric, glass-ceramic surface; Maytag®, Benton Harbor, MI). Then, all of the pasta was added and cooked, uncovered, for the specified amount of time, with occasional stirring to keep the pasta from sticking together (constant stirring was needed during the first 5 min for Treatment M). The pot was removed from heat and the pasta was immediately drained for one minute in a stainless steel colander, with no agitation. The weight of the cooked pasta was taken after it had cooled for approximately 1.5–2 min at room temperature (20 ± 2 °C). For rinsing in Treatment H, 2.84 L cool tap water were slowly poured over the pasta after the initial one-minute draining, then allowed to drain an additional minute after rinsing.

The pasta was homogenized with liquid nitrogen using a 6 L Robot Coupe stainless steel food processor (Robot Coupe 6L Blixer®; Robot Coupe USA, Jackson, MS) and dispensed among six 30-mL glass jars with Teflon™-lined screw-cap lids (~10 g/jar), as described elsewhere (Phillips et al., 2010). The sealed jars were stored at < −55 °C. The uncooked pasta for each experiment was homogenized and dispensed among jars in the same manner.

2.4. Analysis of sodium

Sodium was quantified using inductively coupled plasma spectroscopy-mass spectrometry (ICP-MS) after digesting the samples using a two-day, open vessel, nitric acid/hydrogen peroxide digestion procedure that was a modification of methodology described by Huang and Schulte (1985). All glassware and plastic-ware, with the exception of the syringe filters were first acid-washed by complete immersion in a 20% aqueous nitric acid/DDI water (v/v) bath using Tracemetal™ Grade 70% nitric acid for at least 4 h, followed by copious rinsing with distilled deionized (DDI) water, then HPLC grade acetone, and allowed to air dry beneath lint-free cloth (Kim Wipes™, Kimberly-Clark Professional®, Georgia, USA).

2.4.1. Reagents and standards

Ultrex II® Ultrapure hydrogen peroxide (H_2O_2, 30%) and Ultrex II® Ultrapure 70% nitric acid (HNO_3) (JT Baker®) were purchased from Avantor Performance Materials Inc. (Center Valley, PA, USA). Laboratory grade 2-octanol, HPLC grade acetone, and Tracemetal™ Grade 70% nitric acid were purchased from Fisher Scientific (Pittsburgh, PA, USA). Sodium chloride salt (> 99.999% trace-metal basis) was purchased from Sigma-Aldrich (St. Louis, MO, USA). DDI water was taken through a Barnstead Nanopure II® filtration system (Sybron, Barnstead Cat. #16508) displaying a resistivity reading of at least 18.2 megaohm-cm.

A multi-element standard reference solution with sodium concentration of 100,000 ppb (100 µg/mL) (High-Purity Standards, Charleston, SC) was used to prepare ICP-MS calibration standards, using dilutions at Na^+ concentrations of 0.050, 0.100, 0.500, 1.00, 5.00, 10.0, and 50.0 µg/mL. 100 mL of each standard, with the exception of the lowest concentration were prepared in a 100 mL volumetric flask, diluting the required volume of standard solution to 98 mL with DDI water then bringing to volume with trace metal grade 70% nitric acid. The 0.050 µg/mL solution was prepared by diluting the 5.00 µg/mL standard 1:100.

Six external calibration standard solutions at concentrations of 0.250, 0.500, 1.25, 2.50, 5.00 and 7.50 µg/mL were prepared by diluting a 20 µg/mL sodium chloride standard stock solution in 2% v/v aqueous nitric acid.

2.4.2. Acid digestion

Jars containing the homogenized pasta samples were removed from the freezer and thawed by immersion in a 30 ± 1.0 °C water bath for 20 min. Analytical subsamples were taken, after thoroughly stirring the material using polypropylene spatulas, in amounts that put sodium in the working analytical range: 1.0 ± 0.5 g for uncooked pasta and Treatment B cooked pasta, 1.75 g ± 0.1 g for Treatment G cooked pasta, and 0.5 ± 0.025 g for cooked pasta in all remaining treatments. Each subsample was transferred into a 25 × 150 mm Pyrex® Vista™ test tube (Fisher Scientific, cat# 07-250-119), using a disposable polystyrene spatula (Fisher Scientific, cat# 14-955-550). Two reagent blanks (no sample), were carried through the digestion in each assay batch. After all samples had been weighed, 3.5 mL of nitric acid (70%, JT Baker® Ultrex II®) were added directly to the bottom of each tube, then ~50 µL 2-octanol (to reduce foaming). The tubes were placed into a dry bath incubator (VWR, cat# 13259-038) fitted with six 6 × 25 mm aluminum heating blocks (Fisher Scientific, cat# 11-715-319Q), at room temperature (20 ± 2 °C). The heat was turned on, and the samples were allowed to pre-digest for 30 min until the temperature reached 65 ± 5 °C, during which time additional 2-octanol was added drop-wise as needed to reduce excessive foaming. A total of 3.0 mL 30% hydrogen peroxide were then added, slowly, approximately 1 mL per minute. Once the reaction subsided (~15 min from the last addition H_2O_2), the heat was increased to maintain a temperature of 120 ± 2 °C. An additional 3.0 mL of hydrogen peroxide were added, 1.0 mL/hour, for the next three hours, after which a 25 mm borosilicate watch glass (General Lab. Supply, Pasadena, TX; cat# 110-100) was placed over each tube (to reduce evaporation). The samples were allowed to reflux overnight (~20 h), with DDI water added as needed to rinse down the inside of the tubes and to keep the volume at ~10–15 mL. The following day, the heat was turned down to maintain a temperature between 70 and 80 °C. Each digest was quantitatively transferred to a 20 mL polypropylene syringe (Fisher Scientific, cat# 03-377-24) fitted with a 30 mm diameter, 0.45 µm cellulose acetate filter (Whatman™ Puradisc™Aqua; Fisher Scientific, cat# 10-462-655), and filtered into a class A 25 mL volumetric flask, using DDI water (~20–23 mL total) to quantitatively transfer all traces of the digest into the syringe and flask. The flasks were allowed to sit for about 90 min at room temperature (20 ± 2 °C) before bringing to volume with DDI water. Each sample was then dispensed into a 17 × 100 mm polypropylene culture tube (Fisher Scientific, cat# 14-956-1J), capped, then analyzed by ICP-MS (Section 2.4.3), or held refrigerated (4 °C) and brought to room temperature before analysis.

2.4.3. ICP-MS

Sample digests were analyzed by ICP-MS following Standard Method 3125-B of the American Public Health Association, American Water Works Association, and Water Environment Federation (American Public Health Association, American Water Works Association, and Water Environment Federation, 1998), after diluting to fall within a range of 1–7.5 µg/mL, as follows: no dilution (uncooked pasta and Treatment G), 1:10 (Treatments I-M), and 1:5 (Treatments A-F and H), by pipetting exactly 1.0 or 2.0 mL digest, respectively, into an acid-washed class A 10 mL volumetric flask and taking to volume with DDI water [final nitric acid concentration, 1–5% (v/v)]. The samples and external standards (Section 2.4.1) were analyzed for sodium using a Thermo Electron X-Series inductively coupled plasma mass spectrometer that was calibrated using the multi-element standard solutions ranging from 0.050 to 50.0 µg/mL (Section 2.4.1). The mass/charge for sodium was 23, and ^{6}Li and ^{45}Sc were used as internal standards, both at 10 µg/L concentration, using interpolation.

Sodium concentration was determined using a linear calibration curve constructed from data for the external calibration standards and the reagent blanks with the assayed value for the blanks being set to an expected concentration of 0.

2.5. Method validation and quality control

2.5.1. Method validation

Rigorous validation and testing of the method was performed to ensure accuracy and adequate precision, and lack of bias in sodium quantitation in pasta samples with widely varying concentrations of sodium expected. The optimal sample size and working range for calibration of the ICP-MS were established. An uncooked pasta control composite (CC) of 454 g Barilla®, enriched semolina dry spaghetti was prepared using the method described for homogenization and composite subsampling of the pasta (see Section 2.3), with 44 jars dispensed, as a sample representative of pasta samples low in sodium.

The method was validated for accuracy by analyzing several certified reference materials (RM) with varying sodium content, procured from the National Institute of Standard and Technology (NIST, Gaithersburg, MD): SRM® 3233 Fortified Breakfast Cereal, SRM® 2385 Slurried Spinach, SRM® 2383a Baby Food Composite, SRM®1570a Freeze-Dried Spinach Leaves, and SRM®1548a Freeze-Dried Typical Diet. Additionally, several in-house control composites (CC) used in the USDA's National Food and Nutrient Analysis Program (NFNAP) (Phillips et al., 2006) were analyzed for reference to sodium assayed in foods at other laboratories for the NFNAP. These included a bread/snack food CC (biscuits, whole wheat bread, tortilla chips, corn muffins, pound cake, oat bran muffins, scones), a fortified breakfast cereal, a mixed vegetable composite (canned spinach, potatoes, vegetarian vegetable soup, refried beans, baby food sweet potatoes and corn, salt), a

Table 3
Sodium concentrations (mg/100 g) assayed in commercially available certified reference materials (National Institute of Standards and Technology (NIST), Gaithersburg, MD) and in control materials used in the USDA National Food and Nutrient Analysis Program (Phillips et al., 2006).

	Assayed					Certified[b]	
Material	Mean	Standard Deviation	Relative Standard Deviation (%)	HorRat[a]	n	Mean	Range (mean ± uncertainty)
Certified Reference Materials:							
SRM® 1548a Freeze-Dried Typical Diet	745	0.7	0.1	0.05	2	813	719–907
SRM® 1570a Freeze-Dried Spinach Leaves	1801[c]	11.0	0.6	0.3	2	1821[c]	1798–1844
SRM® 2383a Baby Food	22.3	1.4	6.5	1.8	4	19.5	16.6–22.4
SRM® 2385 Slurried Spinach	5.3	0.2	4.5	1.0	8	4.7	3.7–5.7
SRM® 3233 Fortified Breakfast Cereal	675	12.1	1.8	0.8	6	683	671–695
In-House Control Materials:						Established Median	Range
Bread/Snack Foods[d]	469	15.4	3.3	1.5	34	451	432–471
Breakfast Cereal	689	21.7	3.1	1.5	4	685	658–712
Mixed Vegetables[e]	330	2.8	0.9	0.4	2	321	301–340
Mixed Foods[f]	369	4.2	1.1	0.5	2	351	341–362
Beef Baby Food	34	0.4	1.3	0.4	2	36.9	32.9–40.9
Uncooked Pasta	3.4	0.70	20.3	4.3	45	3.3	2.5–4.0

[a] Ratio of assayed percent relative standard deviation (RSD) to expected RSD, where expected RSD = certified or established mean/100/1000)$^{-0.1505}$) (Horwitz & Albert, 2006).
[b] Certified values for reference materials from certificates of analysis (available from NIST at http://nist.gov/srm/index.cfm); for in-house control materials, established values are based on analyses at independent commercial laboratories as part of the USDA National Food and Nutrient Analysis Program, as described elsewhere (Phillips et al., 2006).
[c] Dry mass basis.
[d] Biscuits, whole wheat bread, tortilla chips, corn muffins, pound cake, oat bran muffins, and scones.
[e] Canned spinach, potatoes, vegetarian vegetable soup, refried beans, baby food sweet potatoes and corn, salt.
[f] Canned chili with and without beans, spaghetti with and without meatballs, red sockeye salmon, and beef stew; frozen chicken and turkey pot pies, lasagna with meat, cheese pizza, pepperoni pizza; hard-boiled egg yolks.

mixed foods composite (canned chili with and without beans, spaghetti with and without meatballs, red sockeye salmon, beef stew, frozen chicken and turkey pot pies, lasagna with meat, cheese pizza, pepperoni pizza, hard-boiled egg yolks), and a beef baby food composite.

Precision within and between assay batches were established by replicate analysis of the RMs, the uncooked pasta CC, and a composite of pasta cooked with salt in the same manner as Experiment A (Table 2). HorRat values, the ratio of the assayed percent relative standard deviation (RSD) to the expected RSD, were calculated according to Horwitz and Albert (Horwitz & Albert, 2006), who postulated an expected RSD equal to 2 * [assayed mean concentration (mg/100 g)/100/1000]$^{-0.1505}$

2.5.2. Quality control

The final dilution of samples for ICP-MS analysis was made to put the sodium concentration assayed by ICP in all samples within a relatively narrow working range on the ICP-MS [1–7.5 µg/mL] to minimize any bias that could occur from quantitation of sodium in digests of samples with low and higher sodium content at the lowest and highest ends of the calibration curve. The calibration standards (Section 2.4.1) were run at the beginning and end of each ICP-MS sequence, and the correlation coefficient (R^2) of the linear calibration curve was calculated using Microsoft Excel 2010 (v. 14.0.7151.5001; Microsoft Corp., Redmond, WA). The calibration was considered acceptable if the RSD for replicates at each concentration were ≤5% and R^2 was ≥0.98.

One sample of each of the bread/snack food CC and uncooked pasta CC were included in each analytical batch to monitor the precision and accuracy across batches, and one reagent blank was placed at the beginning and one at the end of the sample sequence. For each replicate of a given treatment (Table 2), three subsamples of each of the cooked and uncooked pasta were assayed in the same batch (to minimize analytical variability comparing sodium in the cooked and uncooked pasta within experiment). Samples from the replicate experiments of each treatment were assayed in separate batches, to avoid bias among treatments from day-to-day analytical variability.

2.6. Data analysis

The analyzed sodium in the pasta was expressed as mg/100 g. The sodium content per serving of cooked pasta was calculated based on 140 g, the Reference Amount Customarily Consumed (RACC) (Smicklas-Wright, Mitchell, Mickle, Cook, & Goldman, 2002; U.S. Food and Drug Administration, 2016). Means, standard deviations, and 95% confidence intervals for each treatment group, and linear regression were calculated using Microsoft® Excel 14.5.3 (2011) (Microsoft Corporation, Santa Rosa, California). A one-way analysis of variance (ANOVA) and Tukey's pairwise comparison of treatment means (Ott & Longnecker, 2008) ($\alpha = 0.05$) were performed using JMP® Pro 11.2.0 (SAS Institute Inc., Cary, NC).

3. Results

3.1. Method validation and quality control

3.1.1. Limit of detection, limit of quantitation, and analytical sample size

The upper limit for the analytical sample size for all matrices was determined to be approximately 1 g dry matter and < ~30% fat, with a lower limit based on homogeneity of the sample and total digestion volume. Based on these considerations, the maximum sample sizes for dry and cooked pasta were 1 and 1.75 g, respectively. The limit of detection (LOD) on ICP-MS was 0.500 µg/mL and the effective limit of quantitation (LOQ) was 2.00 µg/mL, the lowest concentration that could be measured with acceptable precision both within and between assays. Considering the sample sizes and the minimum final volume of 25 mL solution prepared for ICP, the LOD and LOQ established for sodium in the food samples assayed were 1.25 and 5 mg/100 g, respectively.

3.1.2. Quality control data

Results for the certified RMs and in-house CCs are summarized in Table 3. The ratio of the assayed relative standard deviation (RSD) to the expected RSD (HorRat) was low for all matrices (0.05–1.8), and

within the acceptable range of −2 to 2 described by Horwitz and Albert (Horwitz & Albert, 2006), indicating excellent repeatability. The higher HorRat for the uncooked pasta control is consistent with the mean of 3.4 mg/100 g being below the LOQ of 5 mg/100 g. The assayed mean for each reference material fell within the certified range (mean ± uncertainty) specified in the certificate of analysis. The assayed sodium content of the in-house control materials used in the USDA NFNAP (Haytowitz & Pehrsson, 2018; Phillips et al., 2006) were also within the range and near the median in each case, indicating consistency of sodium determined using the described methodology with sodium values reported in SR (US Department of Agriculture, 2016).

Comparison of results between the multiple assays depends on consistency of quantitation across the assays. Quality control data for the samples of the bread/snack foods and uncooked pasta control materials that were assayed with the experimental samples, showed excellent precision among runs of samples from different treatments, with mean (mg/100 g), RSD, and range (respectively) of 469 (n = 24), 3.5%, and 446–505 for the former and < 5 (n = 21), 23.2%, and 2.8–6.8 for the latter.

For the triplicate analyses of each of the pasta composites cooked with salt, the RSD ranged from 0.3 to 2.2% and the HorRat ranged from 0.1 to 0.8, indicating excellent precision (Horwitz & Albert, 2006). Sodium in the uncooked composites was less than 10 mg/100 g in all experiments (mean, 3.9; median, 3.4; range 2.0–9.2), and was less than the LOQ (5 mg/100 g) in all but five of those composites.

These data also demonstrated the need for analytical quality control to avoid spurious conclusions about treatment effects when samples from different treatments are assayed in multiple analytical runs. It was imperative to define the limits of detection and the between-assay analytical variability to accurately quantify sodium across a wide range of concentrations and to establish the magnitude of the minimum statistically significant treatment difference that could be detected. The distribution of the samples from replicate experiments among different assay batches is important in this context.

3.2. Effects of cooking parameters on sodium content of prepared pasta

3.2.1. Variables with no effect on sodium

Sodium in the uncooked pasta was < 10 mg/100 g in all experiments. Pasta cooked without salt had < 5 mg sodium per serving. Sodium in pasta cooked using the reference method was 176 ± 6 mg/100 g, and the content in pasta cooked with parameters that varied relative to the reference method are summarized in Table 4. Longer cooking time, pasta shape, and whole grain did not affect the sodium content of the cooked pasta [Treatments E, D and L, and F, respectively (Tables 2 and 4)]. Reducing the cooking volume by half, with the same sodium concentration in the water did not result in a difference in sodium in the cooked pasta (Treatment B vs. C).

3.2.2. Variables that decreased sodium

As expected, the lowest sodium content resulted in the pasta cooked without salt (< 5 mg/100 g) (Treatment G). Rinsing after cooking substantially reduced the sodium 34% relative to the reference method (115 vs. 176 mg/100 g).

3.2.3. Variables that increased sodium

The concentration of salt in the cooking water was the predominant factor affecting an increase in sodium in the cooked pasta. The sodium content rose by 91 and 174 mg/100 g when 1.5 and 2 times the amount of salt [54 g (3 Tbsp) and 72 g (4 Tbsp), respectively] were added relative to the reference method (36 g salt) (Treatments I and J). Per serving (140 g) this change doubled the sodium content relative to the reference method, to 490 mg, an increase of more than 10% of the recommended maximum daily intake of 2300 mg. Conversely, using half as much salt or rinsing after cooking decreased sodium by 128 and 162 mg per serving, respectively.

Fig. 1A illustrates the linear relationship and predictive equation for sodium concentration (mg/100 g) in cooked pasta ($[Na]_{pasta}$) as a function of salt concentration (g/L) in the cooking water ($[salt]_{water}$), with a correlation coefficient of 0.9988:

$$[Na]_{pasta} = 27.432 * [salt]_{water} + 3.301$$

Doubling the water to pasta ratio relative to the reference method, to 25.0 (Treatment K), slightly increased the sodium content (17 mg/100 g; 23 mg/140 g serving); however, this amount was not meaningful relative to the recommended daily intake of 2300 mg. Interestingly, reducing the water to pasta ratio did not decrease sodium uptake (Treatment M, Table 4). Thus, an interaction between the ratio of water to pasta and salt concentration is likely, and a substantial increase in sodium in the cooked pasta might occur if the salt concentration in the cooking water was higher than the 6.34 g/L in this test, and if the water to pasta ratio was also greater, which is the case for some recommended methods (Table 1). More research would be needed to determine the combined effect of these two variables.

4. Discussion

4.1. Comparison with other studies

Other reports on the impact of cooking on sodium in pasta are limited. Albrecht, Asp, and Buzzard (Albrecht et al., 1987) studied nutrient retention in different types of pasta, cooked in tap water (8 min), with and without salt and rinsing of the noodles after cooking. A limitation was that the amount of pasta, water, and sodium concentrations in the cooking water (4.4–5.9 g/L), varied amongst the types of pasta, and only one level of sodium was evaluated for each. The amount of pasta (< 100 g) was much less than in the present study and less relative to typical portions that are cooked; the water to pasta ratio (mL/g) was also lower (7.2–8.3 vs. 12.5 for reference method in this study). In another report (Antonelli & Colwell, 2006), sodium was evaluated in different types of pasta cooked on a food service scale, as the intent was to provide guidance for preparation in schools and other public institutions. Compared to the present study, the cooking volume, ratio of water to pasta, and concentration of sodium in the cooking water differed significantly: 2 kg pasta cooked in 11 L water (water to pasta ratio of 5.5 mL/g) and two levels of salt added to the cooking water were tested (0.4 and 4 g, equivalent to 0.7 and 7 g/L), for white spaghetti, penne pasta, and whole wheat spaghetti, compared to the range of 0–12.7 g salt/L and water to pasta ratios of 5.5–25 mL/g in the present study (Table 2). Interestingly, despite all of the differences, the sodium concentrations in the cooked pasta in these studies were consistent with what would be predicted based on the present study considering only the concentration of sodium in the cooking water, as illustrated in Fig. 1B. This predictable relationship suggests that the relationship between sodium concentration in the cooking water and in the cooked pasta established in this study would be applicable across a range of other variables.

4.2. Implications for sodium intake

The RACC for cooked spaghetti is 140 g (U.S. Food and Drug Administration, 2016), equivalent to approximately 1 cup (Smicklas-Wright et al., 2002). Although pasta cooked without salt had < 5 mg sodium per serving [consistent with the < 5 mg/100 g sodium content of dried pasta products (US Department of Agriculture, 2016)], when prepared by a typical method with 36 g (2 Tbsp) salt per 5.68 L (6 qt) water, the content increased to 247 mg per serving, more than 10% of the 2300 mg recommended maximum daily consumption. Even slightly reducing the amount of salt, short of eliminating it altogether, could have a significant impact on sodium intake, considering the amount is more than half of the 400 mg sodium (1 g salt) per day recommended to be eliminated from the diet for reducing CVD risk (Bibbins-Domingo

Table 4
Sodium content of pasta cooked by reference method (Treatment A) and systematic variation of cooking parameters relative to the reference method (see Table 2 for details of Treatments).

Treatment[a]		Sodium in Cooked Pasta, Mean (Standard Deviation)[a]			95% Confidence Interval mg mg/100 g	
Description	Treatment Code (Table 2)	mg/100 g	mg/140 g serving[b]	Difference in sodium (mg/140 g serving) relative to Reference method[c]	Lower	Upper
Reference methods[d]	A	176 (6.0)^{A}	247 (8.4)		169.3	182.9
Amount of salt added to cooking water[e]**:**						
None	G	< 5 (0.6)^{D}	< 5	−248 (−99%)	< 5	< 5
Half the amount	B	91.2 (1.3)^{B}	128 (1.9)	−119(−48%)	89.7	92.7
1.5 times as much	I	267 (8.6)^{E}	373 (12.4)	126 (51%)	256.4	276.3
Twice as much	J	350 (2.6)^{F}	490 (3.5)	243 (99%)	346.9	352.7
Cooking volume and salt concentration:						
Half as much water and pasta half the concentration of sodium in water[e]	C	95.0 (1.8)^{B}	133 (2.5)	−114 (−46%)	93.0	97.0
Amount of pasta (water to pasta ratio, mL/g)[e]**:**						
Half as much pasta (25.0 ratio)[e]	K	193 (12.1)^{C}	270 (16.9)	23 (9.7%)	179.4	206.7
2.3 times as much pasta (5.5 ratio)[e,f]	M	188 (2.3)^{A,C}	263 (3.2)	no change	185.2	190.3
Cooking time and rinsing[e]**:**						
Increased time	E	182 (3.9)^{A,C}	255 (5.5)	no change	177.9	186.8
Rinsing after cooking	H	115 (1.9)^{G}	162 (2.3)	−85 (−34%)	113.6	117.4
Pasta shape:						
Elbow macaroni	D	181 (5.4)^{A,C}	254 (7.5)	no change	175.1	187.3
Angel hair	L	181 (3.3)^{A,C}	254 (4.4)	no change	177.9	185.0
Flour type:						
Whole grain (wheat)	F	185 (4.0)^{A,C}	260 (5.6)	no change	180.8	190.0

[a] Means with different capital letter superscripts differed significantly ($\alpha < 0.05$, $p < 0.05$). Standard deviations are based on the average of the mean for each of n = 3 experiments for each treatment.
[b] Reference Amount Customarily Consumed per eating occasion (U.S. Food and Drug Administration, 2016).
[c] Sodium in pasta cooked per Treatment minus sodium in pasta cooked by reference method (Treatment A).
[d] Reference method included cooking 454 g semolina spaghetti pasta in 5.68 L (6 quarts) water (12.5 water:pasta ratio, with 36 g iodized table salt added to the cooking water, for 9 min (al dente), with draining but no rinsing after cooking (see Table 2 for details of other treatments).
[e] Relative to reference method (Treatment A).
[f] Same ratio as in food service scale study by Antonelli and Colwell (Antonelli & Colwell, 2006).

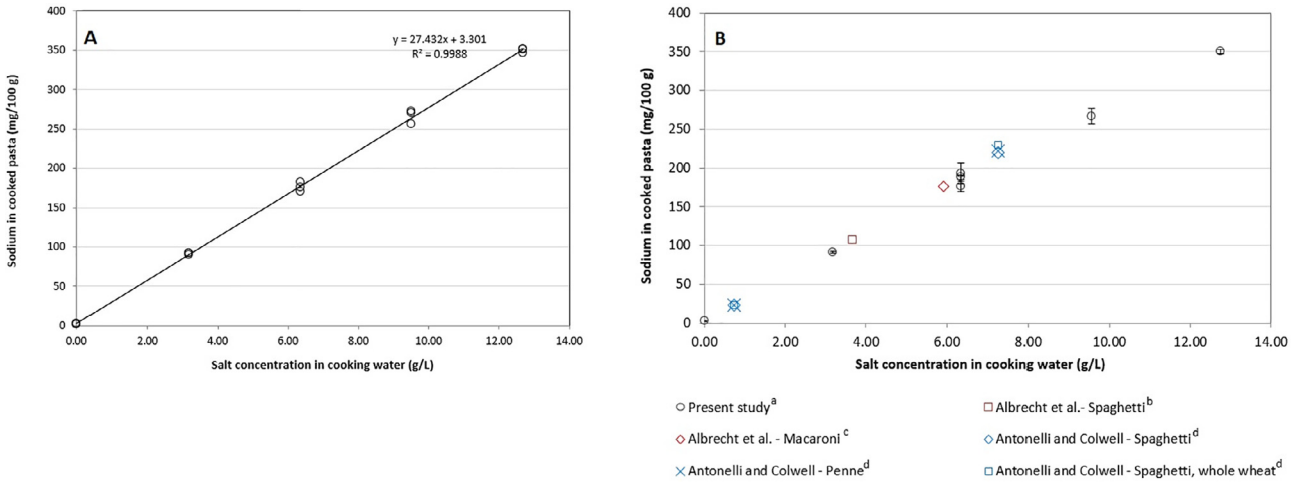

Fig. 1. (A) Sodium content of cooked semolina spaghetti relative to salt concentration in the cooking water Pasta [454 g (1 lb.)] was cooked in 5.68 L (6 qt) water for 9 min (al dente), and drained but not rinsed. (Data from Treatments A, B, G, I, J; Table 2), and (B) compared with other literature reports (Albrecht et al., 1987; Antonelli & Colwell, 2006) for pasta cooked with varying amounts and proportions of water, pasta, and salt. Error bars f indicate the 95% confidence interval for the mean from three replicate experiments in this study. Cooking details for each treatment code are summarized in Table 2. [a]5678 mL water and: 454 g pasta (12.5 mL/g ratio) (Treatments A, B, I, J, G); 227 g pasta (25.0 ratio) (Treatment K); 1032 g pasta (5.5 ratio) (Treamtent M). [b]592 mL water, 71 g pasta (8.3 ratio). [c]473 mL water, 65 g pasta (7.3 ratio). [d]11,000 mL water, 2000 g pasta (5.5 ratio).

et al., 2010). Fig. 2 illustrates the estimated reduction in sodium in cooked pasta prepared by different culinary recommendations and cooking instructions from the package of different brands (Table 1) that could be achieved by using reduced amounts of salt or rinsing after cooking, as predicted by this study based on the salt concentration in the cooking water (Fig. 1A).

The information presented can be used to educate chefs to balance traditional cooking practices with the health benefits of reducing sodium. Although the study did not involve sensory evaluation of the cooked pasta, the wide range of recommended cooking procedures (e.g. Table 1) provides ample flexibility to select methods within culinary norms that result in lower salt content, short of eliminating salt

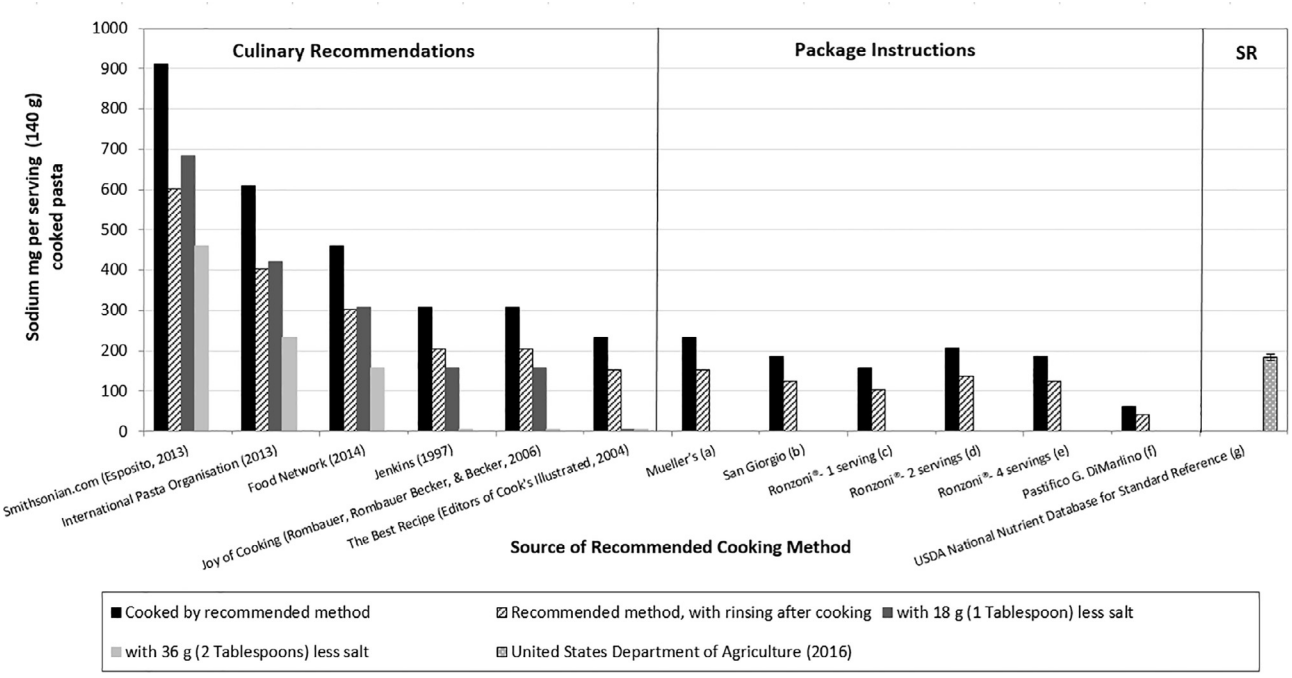

Fig. 2. Predicted sodium content of different brands of semolina spaghetti cooked according to package instructions (Table 1), calculated according to regression equation in Fig. 1A. (SR = USDA National Nutrient Database for Standard Reference (US Department of Agriculture, 2016); 140 g serving size based on Reference Amount Customarily Consumed per eating occasion (U.S. Food and Drug Administration, 2016). [a]Pasta 454 g, water 3.8 L, salt 18 g, cooking time 10–11 min. [b]Pasta 454 g, water 4.7 L, salt 18 g, cooking time 9 min. [c]Pasta 114 g, water 1.9 L, salt 6 g, cooking time 10 min. [d]Pasta 247 g; water, 2.8 L; salt, 12 g; cooking time, 10 min. [e]Pasta 454 g, water 4.7 L, salt 18 g, cooking time 10 min. [f]Pasta 500 g, water 4.7 L, salt 6 g, cooking time 8 min. [g]Database mean ± standard error (NDB #20521, Pasta, cooked, unenriched, with added salt) (US Department of Agriculture, 2016).

altogether, as well as consideration to introduce rinsing after cooking.

4.3. Food composition data and dietary intake estimates

SR (US Department of Agriculture, 2016) is the source of food composition data for epidemiological studies relating nutrient intake with health outcomes in conjunction with the WWEIA NHANES (Centers for Disease Control, 2007) and other instruments that are used to shape U.S. dietary guidelines and to plan public health messages. While the USDA is continually reviewing and updating nutrient concentration of foods, it is impossible for SR to include sodium data for pasta cooked by all possible methods. Currently SR contains data for pasta cooked with salt (NDB #20321) and without salt (NDB #20121). The SR average value for sodium in pasta cooked with salt (131 ± 8.6 mg/100 g or 183 mg ± 12 mg/140 g serving) is the average for preparation by different methods, including a wide range of salt concentration in the cooking water (3.6–6.8 g/L), yet culinary recommendations include cooking in water with salt concentrations up to 12.7 g/L (Table 1). Since the concentration of salt in the water has a marked effect on the sodium content of the cooked pasta, sodium intake could be significantly under- or overestimated using the average value, depending on how the pasta was actually prepared in a given population or among individuals. One might also hypothesize that, given the culinary recommendations encompassing a higher concentration of salt than package instructions for dry pasta (Table 1), that sodium in pasta at restaurants would be substantially higher than the database average.

The predictive equation for sodium in cooked pasta as a function of the salt concentration in the cooking water (Fig. 1A) could be used by researchers to calculate sodium content based on differing amounts of salt added during pasta preparation, and whether or not the pasta was rinsed. The variation in sodium content of cooked semolina spaghetti, calculated for different brands prepared according to the package instructions (Table 1) for pasta cooked with salt, that were presented in Fig. 2, shows substantial differences relative from the SR value of 283 mg/140 g serving, and are more than 10 mg below the mean minus standard error (241 mg/100 g) in all but one case (ranging from 34 to 178 mg less per serving). These data further illustrate the significant impact that discretionary and variable amounts of salt used in cooking pasta can have on sodium intake, and on dietary intake estimates using food composition average values.

5. Limitations

Variables other than the amount of salt added to the cooking water and the water to pasta ratio had only one variation relative to the reference method, limiting the ability to determine trends for those parameters. Interactions between variables also were not tested, and only one brand of spaghetti was tested. However, it was clear that the main determinant of sodium in the cooked pasta was consistent across many cooking conditions, and the relationship established in this study predicted well the values determined in other published studies that used discrete and different cooking parameters and pasta samples, suggesting that estimation of sodium in prepared pasta using the concentration of salt in the cooking water would be a reasonable approach.

6. Conclusion

Dry pasta is itself low in sodium, but significant and varying sodium content results from salt added during preparation. Reducing (or eliminating) the amount of salt added when cooking pasta and/or rinsing after cooking is a simple and quantitative way to reduce dietary sodium. The purpose of salt in cooking pasta is generally agreed upon to be for taste (Editors of Cook's Illustrated, 2004; Esposito, 2013; The Food Network, 2014; International Pasta Organisation, 2016; Jenkins, 1997). The linear relationship between the concentration of salt in the cooking water and sodium in the prepared pasta (Fig. 1A) can be used to obtain a more accurate estimate of the sodium content than the average food composition database value for "pasta cooked with salt",

for pasta cooked with known amounts of salt and water. This information could also be communicated to consumers as demonstrable and simple way to reduce sodium intake, by relating how much salt in pasta cooking water increases sodium, and that rinsing after cooking could reduce by 1/3 the sodium content of pasta cooked in salted water. It would be valuable to add questions to dietary surveys aimed at assessing sodium intake on water volume, amount of salt, and whether rinsing was performed in cooking pasta. Other foods listed in WWEIA NHANES as likely to have salt added in preparation include eggs, rice, fresh/frozen vegetables, and legumes (Quader et al., 2017). Sodium uptake from salt added during cooking could be similarly be evaluated.

Declarations of interest

None.

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