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Why vegetable recipes are not very spicy

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Abstract

Spices are aromatic plant materials that are used in cooking. Recently it was hypothesized that spice use yields a health benefit: cleansing food of parasites and pathogens before it is eaten, thereby reducing food poisoning and foodborne illnesses. In support, most spices have antimicrobial properties and use of spices in meat-based recipes is greatest in hot climates, where the diversity and growth rates of microorganisms are highest. A critical prediction of the antimicrobial hypothesis is that spices should be used less in preparing vegetables than meat dishes. This is because cells of dead plants are better protected physically and chemically against bacteria and fungi than cells of dead animals (whose immune system ceased functioning at death), so fewer spices would be necessary to make vegetables safe for consumption. We tested this corollary by compiling information on 2129 vegetable-only recipes from 107 traditional cookbooks of 36 countries. Analyses revealed that spice use increased with increasing ambient temperature, but less dramatically than in meat-based recipes. In all 36 countries, vegetable dishes called for fewer spices per recipe than meat dishes; 27 of these differences were significant. Of 41 individual spices, 38 were used less frequently in vegetable recipes; 30 of these differences were significant. Proportions of recipes that called for >1 spice and >1 extremely potent antimicrobial spice also were significantly lower for vegetable dishes. By every measure, vegetable-based recipes were significantly less spicy than meat-based recipes. Within-country analyses control for possible differences in spice plant availability and degrees of cultural independence. Results thus strongly support the antimicrobial hypothesis. © 2001 Elsevier Science Inc. All rights reserved.

Keywords: Spices; Antimicrobial hypothesis; Cookbooks; Vegetable-based recipes; Meat-based recipes; Secondary compounds; Foodborne illnesses; Darwinian gastronomy

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1. Background

Spices are aromatic plant materials. They come from woody shrubs or vines, aromatic lichens, parts of trees, and the roots, flowers, seeds, or fruits of herbaceous plants (Farrell, 1990). For thousands of years, spices have been used in food preparation and preservation, as well as embalming, aiding digestion, lowering blood pressure, and increasing sexual potency (Dillon & Board, 1994; Govindarajan, 1985; Hirasa & Takemasa, 1998). During the Middle Ages and after, hazardous voyages were undertaken by famed seafarers like Marco Polo, Ferdinand Magellan, and Christopher Columbus to establish routes to trading ports in primary spice-growing regions (Parry, 1953). Spice trade was so crucial to national economies that rulers repeatedly mounted costly expeditions to raid spice-growing countries, and struggles for their control precipitated several wars (Dalby, 2000).

Today, the spice trade is still big business. For example, black pepper is the world's most widely used spice even though *Piper nigrum* grows only in a small number of tropical countries. In a recent year (1991), nearly 87 million pounds of pepper were imported to the United States alone (Tainter & Grenis, 1993). Vast quantities of chili peppers also are traded yearly (Govindarajan, Rajalakshmi, & Chand, 1987).

An intriguing aspect of spice use is its variability among cultures: Some cuisines make frequent use of multiple spices, whereas others use spices sparingly if at all (e.g., Billing & Sherman, 1998; Dalby, 2000; Hirasa & Takemasa, 1998). There has been considerable interest in and discussion of what causal factors might underlie such variations, but no consensus has been reached (Govindarajan, 1985; Johns, 1990; Rozin, 1982, 1990; Sass, 1981). It is clear, however, that the variations are not due solely to local differences in spice plant availability (Billing & Sherman, 1998).

Use of spices involves both benefits and costs. On the positive side, spices are natural pharmaceuticals. Spice plants contain chemicals that evolved to deter or eliminate their biotic enemies, both macroscopic (e.g., insects) and microscopic (bacteria and fungi: Walker, 1994). Not surprisingly, therefore, these "secondary compounds" (secondary to plants' basic metabolism) have antimicrobial properties (Baratta et al., 1998; Beuchat, 1994; Hirasa & Takemasa, 1998; Nakatani, 1994). Recently it was hypothesized that an important benefit of spice use is cleansing food of parasites and pathogens before it is eaten, thereby reducing chances of contracting foodborne illnesses immediately (Billing & Sherman, 1998; Sherman & Billing, 1999) or after prolonged food storage (Brul & Coote, 1999).

On the negative side, in high concentrations phytochemicals can be allergens, carcinogens, teratogens, and abortifacients (e.g., Ames, Profet, & Gold, 1990; Beier & Nigg, 1994; Surh & Lee, 1996). These potential dangers help explain why spices generally are used sparingly, and typically are avoided entirely by preadolescent children (Cashdan, 1998) and pregnant women (Flaxman & Sherman, 2000; Profet, 1992), i.e., because rapid cell division is going on within these individuals, they are especially susceptible to mutagens and teratogens. Aversions to spicy foods during adolescence and gestation may thus serve a common, prophylactic function.

The antimicrobial hypothesis proposes that humans borrow the spice plants' protective chemicals to inhibit or eliminate their own biotic enemies. This hypothesis predicts that spice use should be more prominent in hot than cool climates because the diversity of foodborne pathogens and rates at which they proliferate both increase with increasing temperature (e.g., Bryan, 1988; Giese, 1994; Hui, Gorham, Murrell, & Cliver, 1994). In support, analyses of 4578 meat-based recipes (i.e., $\geq 1/3$ meat by weight or volume) in 93 traditional cookbooks from 36 countries revealed that as average annual temperatures increased, so did proportions of recipes containing ≥ 1 spice, numbers of spices per recipe, use of the most potent antibacterial spices, and proportions of foodborne bacteria species inhibited per recipe (Billing & Sherman, 1998; Sherman & Flaxman, 2001).

The antimicrobial hypothesis assumes that concentrations of spices used in cooking are sufficient to produce the desirable effects. Analyses of spice concentrations in prepared dishes and their combined antibacterial potency, which are necessary to evaluate this assumption, are just beginning (see Board & Gould, 1991; Rusul, Chun, & Radu, 1997). However, recipes generally call for 0.25–3.0 g of spices/kg of primary ingredients (i.e., 250–3000 ppm), which is well within the range of concentrations that kill or inhibit foodborne bacteria in laboratory tests (e.g., Hirasa & Takemasa, 1998; Ismaiel & Pierson, 1990). This implies that concentrations of spices used in cooking are sufficient to yield useful antibacterial effects, as suggested by Giese (1994), Hirasa and Takemasa (1998), Liu and Nakano (1996), and Shelef (1984).

The antimicrobial hypothesis also assumes that cooking does not destroy plant secondary compounds. On the one hand, Chen, Chang, and Chang (1985) and Srinivasan, Sambaiah, and Chandrasekhara (1992) reported that cooking eliminated the antimicrobial effects of some spices (e.g., cumin), whereas others were unaffected (e.g., capsaicins). On the other hand, commercial extraction of spice oleoresins and essential oils often involve steam distillation at extremely high temperatures. Gas chromatograms that compare steam distilled spice chemicals against CO_2 extracted products typically show similar patterns (Moyler, 1994), indicating that those spices are thermostable. Further, Diebel and Banawart (1984) found that oregano, sage, and ground cloves still inhibited *Campylobacter jejuni* (a major cause of gastroenteritis) after 16 h of simmering at both 25°C and 42°C. Apparently, spice chemicals are not usually destroyed by cooking (Moyler, 1994).

A critical but untested prediction of the antimicrobial hypothesis is that spices should be used less in vegetable than meat recipes. This is because foodborne microorganisms do not survive or proliferate as well in vegetables, so adding spices is not as necessary. Cells of dead plants are naturally better protected from microbial invasions than cells of dead animals, because (i) many vegetables contain inhibitory phytochemicals, including protease inhibitors, chitinases, gluconases, phenolics, and ribosome-activating proteins (Darnetty, Muthukrishnan, Swegle, Vigers, & Selitrennikoff, 1993; Mansfield, 1983; Schlösser, 1997), (ii) plants have specially modified cell walls containing cellulose and lignin, which makes them difficult for most aerobic microorganisms to decompose (Banwart, 1989; Heitefuss, 1997; Rapp & Beermann, 1991); indeed, lignin is synthesized specifically to surround bacterial and fungal infections and arrest their spread (Ride, 1983; Vance, Kirk, & Sherwood, 1980), and (iii) the pH range of plant cells (4.3–6.5) is below ideal growth conditions for most bacteria (i.e., pHs of 6.6–7.5; Jay, 1992). In contrast, cells of dead animals are relatively unprotected chemically and physically, and their internal pH usually is >5.6. The primary defense mechanism of an animal's cells, its immune system, ceases functioning at death. These considerations explain why meat products are more often associated with outbreaks of foodborne illnesses than vegetables, especially in hot climates (Sockett, 1995; Todd, 1994).

To test for the predicted difference in spiciness of vegetable- and meat-based recipes, we gathered information on frequencies and types of spices used in vegetable dishes and compared them with meat dishes from the same countries. Our within-country analyses sidestep two general problems that frequently obfuscate interpretations of crosscultural studies (Hartung, 1982; Mace & Pagel, 1994): (i) cultures may not be equally independent, for example due to shared ancestry or recent immigration and (ii) raw materials used in the cultural practices under study (in this case, spices) may not be equally available everywhere. Since these problems are avoided, our results constitute a more robust test of the antimicrobial hypothesis than has previously been possible.

2. Methods

We compiled lists of all the spices called for in the vegetable-based recipes of traditional cookbooks from the same 36 countries whose meat-based recipes were analyzed previously by Billing and Sherman (1998). The countries (Table 1) lie on six continents and represent 16 of the world's 19 major linguistic groups (Ruhlen, 1987). For each country, the mean annual temperature was calculated by averaging data from all major cities listed in Conway and Liston (1990).

A vegetable-based recipe was one consisting of $\geq 1/3$ vegetables by weight or volume, and including no meats or condiments containing meat products (e.g., Worcestershire sauce, oyster sauce). "Vegetables" were plant parts, including roots, stems, leaves, fruits, tubers, and seeds. Onions were considered to be both "vegetables" and "spices" when they were the main ingredient in a recipe (i.e., constituting $\geq 1/3$ of its weight or volume), but only spices when they were called for in smaller quantities. Rice, wheat, and other grains and grain-based dishes (i.e., plain spaghetti) were not considered vegetables. Information from all categories of recipes was tabulated (e.g., main courses, side dishes, appetizers) with two exceptions: Soup recipes were omitted because many called for meat-based stocks and others did not state what type of stock was required, and desserts were omitted because very few called for vegetables.

We considered a cookbook to be "traditional" if the author stated that his/her purpose was to record that country's cuisine for posterity. Authors often were native to or had lived in the country, and our sources frequently were English translations of native language cookbooks. We avoided avant-garde and modern cookbooks, and those written primarily for North American audiences (as indicated by the title or preface). Of course, cookbooks were selected "blind" relative to the frequency with which they called for spices. To minimize possible effects of authors' biases (e.g., preferences for spicy or bland recipes), we consulted at least two traditional cookbooks for each country. These always deviated $< 5\%$ in the mean number of spices per recipe and the identities of all spices used in that country. For a few countries, more than two cookbooks were available, and in these cases, we randomly chose two for analyses.

Some countries include regions that differ greatly in latitude and altitude, resulting in major differences in annual temperatures. Potentially, this presented opportunities to assess variations in spice use in different climatic regions. Unfortunately, however, we were able to locate

Table 1
Within-country comparisons of spice use in traditional vegetable- and meat-based recipes

Country	Mean annual temperature (°C)[a]	Number of recipes examined		Mean number of spices/recipe (±S.D.)			Proportion using ≥1 spice		Proportion using ≥1 highly antimicrobial spice[b]	
		M[c]	V[d]	M	V	Significance[e]	M	V	M	V
Norway	2.8	77	25	1.6 ± 1.1	1.1 ± 0.9	n.s.	0.67	0.76	0.12	0.13
Finland	3.0	62	28	2.1 ± 1.4	0.6 ± 0.6	.001	0.69	0.50	0.16	0.07
Sweden	5.4	134	46	2.5 ± 1.4	1.2 ± 0.9	.001	0.88	0.83	0.28	0.07
Poland	7.8	141	119	3.2 ± 1.9	1.3 ± 1.1	.001	0.73	0.71	0.31	0.09
Denmark	8.3	87	28	1.9 ± 1.2	0.7 ± 0.6	.001	0.74	0.61	0.27	0.07
Austria	8.8	188	113	2.7 ± 1.4	1.9 ± 1.3	n.s.	0.89	0.87	0.20	0.08
England	8.8	223	35	2.1 ± 1.2	1.5 ± 1.0	n.s.	0.93	0.89	0.17	0.18
Germany	8.8	169	63	3.2 ± 1.7	1.4 ± 1.2	.001	0.91	0.73	0.23	0.07
Ireland	9.6	90	30	3.2 ± 2.3	2.0 ± 1.6	n.s.	0.73	0.97	0.22	0.12
Hungary	10.3	80	47	3.0 ± 1.6	2.4 ± 1.5	n.s.	0.93	0.87	0.32	0.15
France	12.1	216	63	3.9 ± 2.5	2.5 ± 1.5	.001	0.99	0.94	0.28	0.12
Korea	12.1	81	68	3.5 ± 0.9	1.7 ± 1.5	.001	0.87	0.74	0.42	0.33
Italy	14.0	86	68	3.4 ± 2.2	2.2 ± 1.2	.05	0.95	0.92	0.24	0.10
Japan	14.3	103	40	2.1 ± 1.3	0.7 ± 0.8	.001	0.73	0.60	0.26	0.11
Portugal	15.0	84	27	4.5 ± 2.2	2.5 ± 1.5	.001	0.97	0.85	0.26	0.14
Greece	16.7	118	108	4.4 ± 2.0	4.2 ± 1.6	n.s.	1.00	0.98	0.23	0.14
Iran	16.7	85	47	5.0 ± 1.4	3.0 ± 1.2	.001	1.00	0.97	0.37	0.19
South Africa	17.2	108	125	2.6 ± 1.6	1.2 ± 1.0	.001	0.87	0.72	0.20	0.06
Morocco	18.3	104	47	5.8 ± 1.9	4.4 ± 2.2	.01	1.00	1.00	0.51	0.29
Australia	18.6	64	99	3.4 ± 1.6	1.8 ± 1.4	.001	0.96	0.88	0.20	0.10
Israel	19.1	145	105	3.9 ± 1.8	2.3 ± 1.6	.001	0.96	0.89	0.31	0.09
Lebanon	20.6	98	69	4.7 ± 1.6	3.7 ± 1.6	.05	0.97	0.99	0.45	0.31
Ethiopia	21.1	56	25	7.5 ± 2.8	6.9 ± 4.2	n.s.	1.00	1.00	0.63	0.40
Kenya	22.1	73	37	5.4 ± 3.3	3.0 ± 2.6	.001	1.00	0.88	0.43	0.22
Mexico	23.1	123	43	4.4 ± 1.9	2.4 ± 1.2	.001	0.98	0.98	0.29	0.23
Brazil	23.9	132	37	4.2 ± 1.9	1.7 ± 1.2	.001	0.98	0.86	0.47	0.16
Vietnam	24.6	84	28	4.5 ± 1.7	1.5 ± 2.1	.001	0.98	0.80	0.37	0.24
Ghana	25.9	95	58	2.2 ± 1.0	0.8 ± 1.0	.001	0.98	0.45	0.25	0.07
Nigeria	26.5	82	28	2.4 ± 1.6	1.4 ± 1.0	.001	1.00	0.74	0.56	0.23
Indonesia	26.8	120	44	6.9 ± 2.3	4.1 ± 1.9	.001	1.00	1.00	0.46	0.35
India	26.9	91	80	9.3 ± 3.6	6.5 ± 4.2	.01	1.00	0.95	0.60	0.43
Malaysia	26.9	60	32	5.4 ± 2.1	3.2 ± 2.6	n.s.	1.00	0.94	0.33	0.31
Philippines	27.0	118	31	3.0 ± 1.4	1.8 ± 1.1	.001	0.98	0.86	0.35	0.27
Thailand	27.6	118	27	4.2 ± 1.4	3.2 ± 2.8	n.s.	1.00	0.77	0.40	0.26
USA-North	8.6	284	139	5.4 ± 2.7	1.6 ± 1.4	.001	0.90	0.81	0.36	0.06
USA-South	17.8	169	85	5.0 ± 2.3	2.8 ± 1.8	.01	0.99	0.91	0.32	0.18
China-NE	13.4	187	46	2.3 ± 1.8	1.6 ± 1.1	.05	0.90	0.85	0.50	0.13
China-SW	19.4	243	38	3.2 ± 1.6	2.3 ± 1.6	n.s.	0.93	0.95	0.50	0.35

[a] Listed in order of increasing temperature; climate data are from Bair (1992) and Conway and Liston (1990).
[b] Spices that inhibit ≥75% of bacterial species they have been tested on.
[c] Meat-based recipes (data from Billing & Sherman, 1998).
[d] Vegetable-based recipes.
[e] Two-tailed *t* tests.

traditional regional cookbooks only for China and the United States. Northern and eastern China have similar (continental) climates, with hot summers, cold winters, and little precipitation; southern and western China also have similar (subtropical) climates, with hot, humid summers, mild winters, and moderate rainfall. We calculated the mean annual temperature and precipitation for the cities of Lanzhou, Beijing, Tianjin, Shenyang, and Shanghai in northeast China, and Kunming, Changsha, Hankow, Chungking, Canton, and Nanning in the southwest using data in Bair (1992) and Conway and Liston (1990). In the United States, we characterized northern climates using Bair's data for the cities of Buffalo, New York, Pittsburgh, Portland, San Francisco, Sault St. Marie, Washington, DC, Fairbanks, and Juneau; southern climates were characterized using data for Albuquerque, Asheville, Atlanta, Austin, Birmingham, Brownsville, El Paso, Jacksonville, Los Angeles, Louisville, Miami, Nashville, New Orleans, and Phoenix.

Before data gathering began, we decided to sample ≥ 25 vegetable-based recipes per country. For 27 countries (and 95% of all the vegetable-based recipes we analyzed), this minimum sample size was met or exceeded in the same 93 cookbooks used previously (for references, see Table 1 of Billing & Sherman, 1998). However, because vegetable-based recipes were less numerous than meat dishes, to achieve our quota we had to consult 1–3 additional cookbooks for nine countries, namely Denmark (Palsbo, 1961), Ethiopia (National Literacy Campaign Organization, 1960; Odarty, 1971), Finland (Tolvanen, 1960), Malaysia (Selva Rajah, 1996; Soo, 1992; Yew, 1982), Norway (Scott, 1995), the Philippines (Weaver, 1978), Portugal (Marques, 1956; Robertson, 1993), Sweden (Coombs, 1958), and Vietnam (Choi & Isaak, 1997; Miller, 1968). In total, our sample comprised 2129 vegetable-based recipes (Table 1).

For all 36 countries, every spice called for in each recipe was recorded, regardless of its form (fresh or dried, chopped, etc.) or quantity. Usually, recipes specified small amounts of powdered spices or spice oils. When a recipe called for either of two spices we counted only the first one listed; spices identified as "optional" were not included. Spices were grouped for analyses according to the chemical components of their essential oils (Farrell, 1990). Thus, "onions" included leeks, chives, shallots, and onions; "pepper" included black and white pepper (mostly black); and "chilis" included all capsaicin-containing peppers (green peppers and paprika were not included because they have been selected to contain minimal capsaicin).

For every country's vegetable-based recipes, we calculated the total number of different spices called for in all the recipes, proportions that called for ≥ 1 spice, mean ($\pm$S.D.) numbers of spices per recipe, and proportions that called for ≥ 1 highly antimicrobial spice. The latter were the 15 spices that inhibited or killed ≥ 0.75 of species of foodborne bacteria that they have been tested on in the laboratory (Billing & Sherman, 1998; Hirasa & Takemasa, 1998), including garlic, onion, allspice, oregano, thyme, cinnamon, tarragon, cumin, cloves, lemon grass, bay leaf, chilis, rosemary, marjoram, and mustard.

For each spice-use parameter, we tested the null hypothesis that differences between meat- and vegetable-based recipes among all countries combined were distributed randomly (i.e., meat-based recipes were more spicy than vegetable-based recipes as often as the reverse) using the nonparametric Wilcoxon's signed-rank test (Sokal & Rohlf, 1995). Proportional differences in the use of individual spices in meat- and vegetable-based recipes were analyzed with nonparametric G tests. Two-tailed t tests were used to compare numbers of spices/recipe in meat- and vegetable-based dishes within each country, and to determine if there were differences in spice use between meat- and vegetable-based recipes among countries. Analysis of covariance was used to compare differences in rates of increase in spice use between meat- and vegetable-based dishes as a function of climate (temperature). Statistical tests were conducted using Minitab 10.5 on an IBM compatible PC.

3. Results

Among all 36 countries in our sample (Table 1), traditional vegetable-based recipes called for a mean of 2.4 ± 1.4 spices. This was significantly fewer than the 3.9 ± 1.7 spices/recipe called for in traditional meat-based recipes from the same countries ($t = -4.00$, $P < .001$).

Relative frequencies of use of 41 individual spices were similar in vegetable- and meat-based recipes, i.e., the curves for both types of dishes approximated negative exponentials and the same seven spices were used most commonly in both (Fig. 1). However, the vast majority of spices ($38/41 = 0.93$) were used less frequently in vegetable-based recipes ($P < .001$, Wilcoxon's signed-rank test), and 30 of the 38 differences in proportional use of individual spices were significant (i.e., all $P < .01$, G tests).

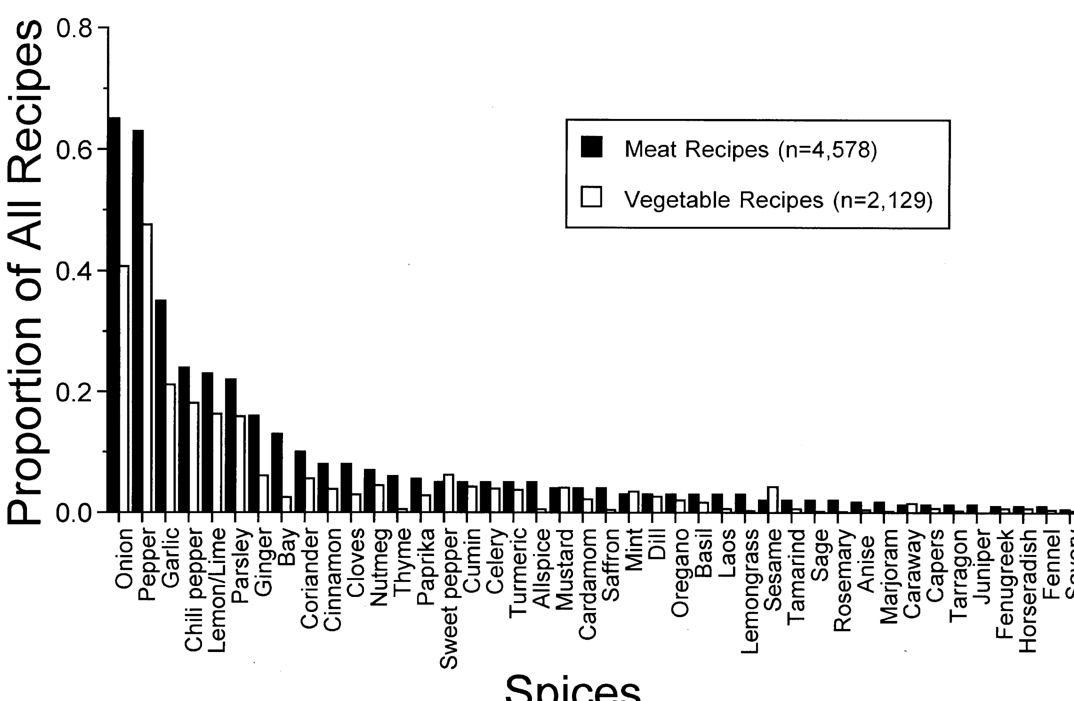

Fig. 1. Proportions of 4578 meat-based recipes (filled bars) and 2129 vegetable-based recipes (open bars) from traditional cookbooks of 36 countries that called for each of 41 spices. Countries and sample sizes are listed in Table 1. Data on meat-based recipes are from Billing and Sherman (1998).

Within countries, vegetable-based recipes called for fewer spices than meat-based recipes in 34 of 34 countries (Table 1; Fig. 2), and in all four major culinary regions of China and the

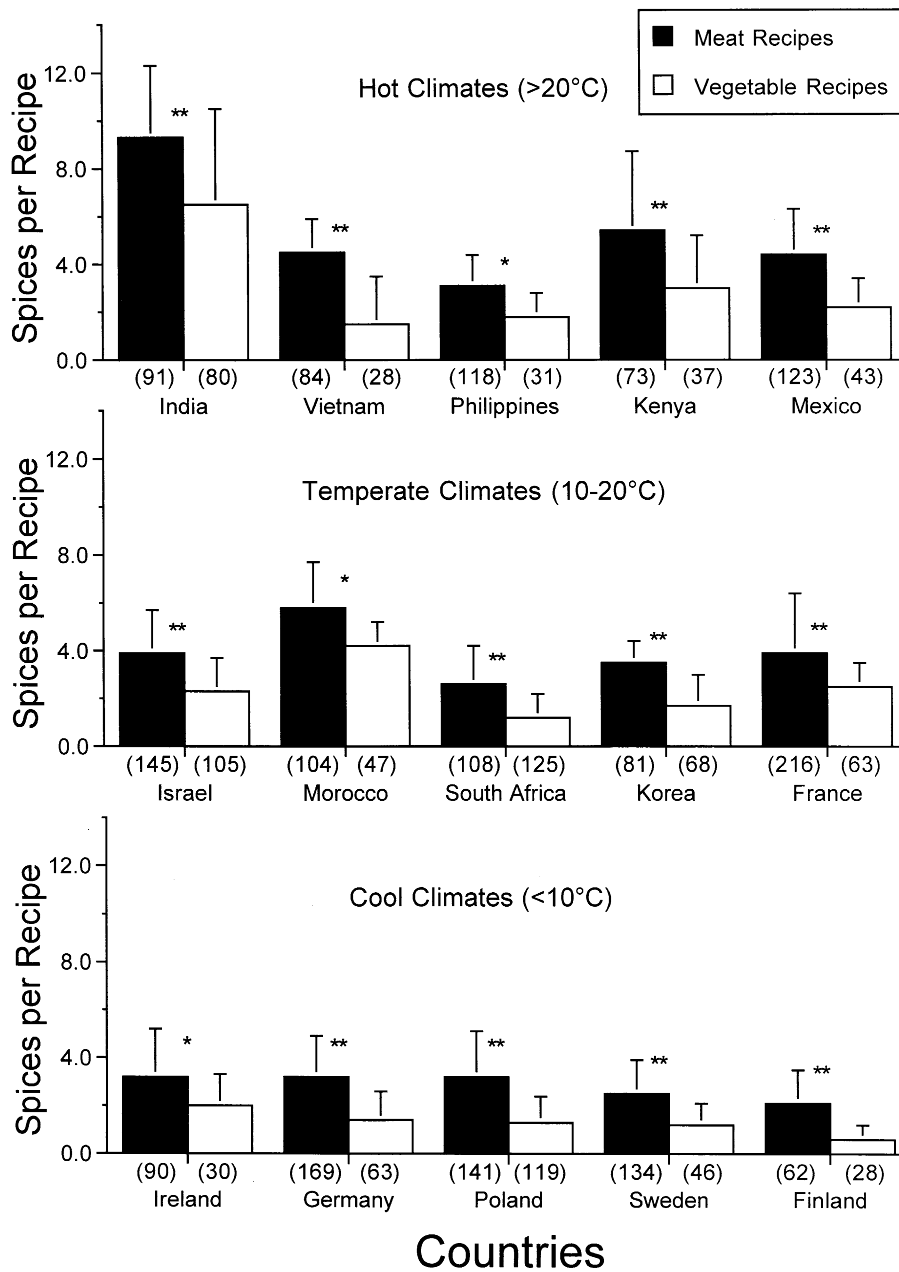

Fig. 2. Numbers of spices called for in meat-based (filled bars) and vegetable-based (open bars) recipes in traditional cookbooks from 15 countries in three climatic regions. Histograms depict mean numbers of spices ($\pm$S.D.) per recipe; significance of intracountry comparisons are indicated (two-tailed t tests, $**P<.001$, $*P<.01$). Numbers of recipes analyzed per country are indicated in parentheses.

United States. The probability that this result could be due to chance is $<.0001$ (Wilcoxon's test). For 25 of 34 countries (0.74) and three of four culinary regions in China and the United States, these differences in numbers of spices/recipe were significant (Table 1).

Proportions of recipes that called for ≥ 1 spice were lower for vegetable- than meat-based recipes in 27 of 34 (0.79) countries and in all four culinary regions of China and the United States ($P<.005$, Wilcoxon's test). Proportions of recipes that called for ≥ 1 of the 15 highly antimicrobial spices were lower for vegetable- than meat-based dishes in 32 of 34 (0.94) countries, and in all four culinary regions of China and the United States ($P<0.005$, Wilcoxon's test). In summary, by every measure vegetable-based recipes called for significantly fewer spices than meat-based recipes.

Within a country, recipes involving the same major food item undoubtedly are not completely independent. We therefore reanalyzed the data, this time reducing pseudoreplication by lumping each country's meat- and vegetable-based recipes according to major food items. Four main ingredient categories emerged (i.e., containing ≥ 5 recipes/category/country): For meats, these were beef, pork, chicken, and fish, and for vegetables, the

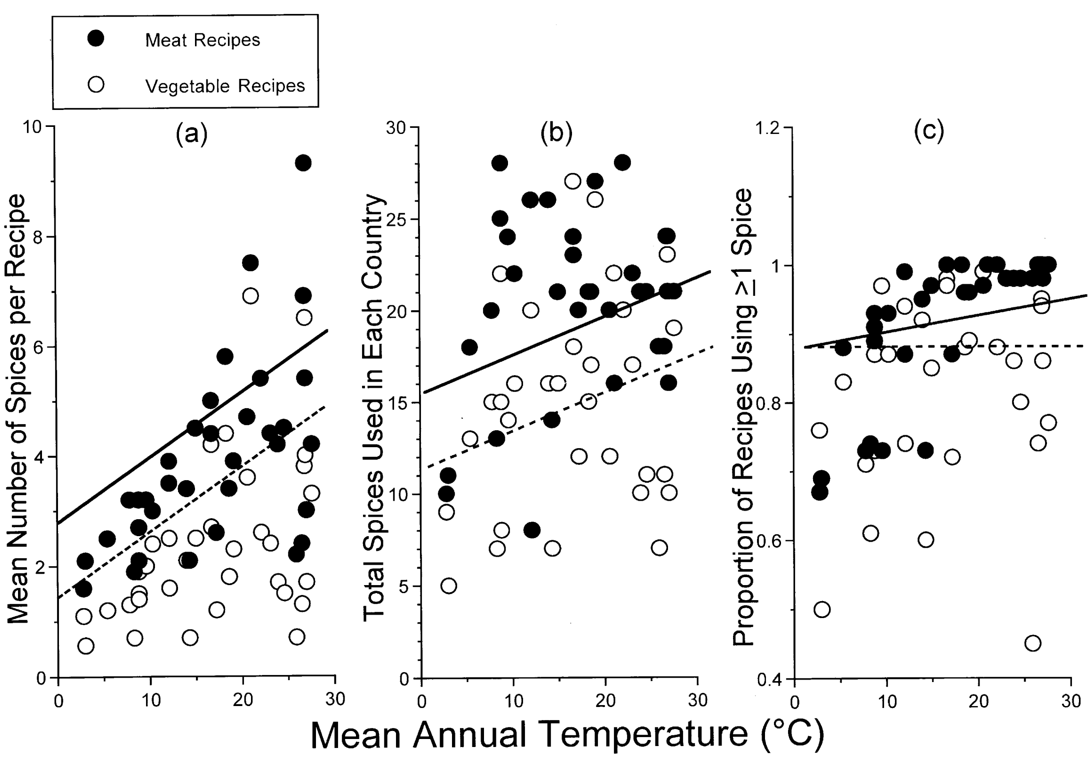

Fig. 3. Relationships between mean annual temperatures and spice use in traditional meat-based (filled circles) and vegetable-based recipes (open circles) from 34 nonregional countries (i.e., not including China and the United States). Lines are from ANCOVA analyses (see text for significance levels) of each data set: (a) mean numbers of spices/recipe (meat-based: $y=0.11x+1.9$; vegetable-based: $y=0.11x+0.4$), (b) total numbers of spices used in each country (meat: $y=0.20x+$ 17.1; vegetables: $y=0.20x+11.8$), and (c) proportion of recipes in each country that used at least one spice (meat: $y=0.01x+0.8$; vegetables: $y=0.8$).

categories were carrots, potatoes, beans, and corn. Using these categories, we compared the total numbers of different spices used in all recipes, numbers of different spices per recipe, proportions of recipes containing ≥ 1 spice, and proportions of recipes containing ≥ 1 highly antimicrobial spice. By all four measures, the four vegetable-based categories of recipes, considered together, were significantly less spicy than the four meat-based categories (all $P < .02$, Mann–Whitney U tests).

Among the countries in our sample, use of spices increased with increasing ambient temperatures in both meat- and vegetable-based recipes (Fig. 3). However, across the temperature spectrum, vegetable-based recipes called for (i) significantly fewer spices/recipe than meat-based recipes (i.e., in Fig. 3a, the Y intercept differed [$P < .001$], but the slopes did not differ [$P = .266$], ANCOVA), and (ii) significantly fewer total spices (in Fig. 3b, the intercepts differed [$P < .001$], but the slopes did not differ [$P = .520$]). Proportions of recipes calling for ≥ 1 spice were equally low for meat- and vegetable-based dishes in countries with cool climates (i.e., in Fig. 3c, the intercepts did not differ [$P = .741$]), but proportions of recipes with ≥ 1 spice increased faster for meat- than vegetable-based dishes as annual temperatures increased (i.e., in Fig. 3c, the slopes differed [$P < .001$]).

4. Discussion

Crosscultural analyses always confront "Galton's problem" (Hartung, 1982): How to select societies for comparison that adequately represent the range of cultural variation but minimize cases where similarities are due to recent common derivation or diffusion. Independence of data points is desirable statistically but, as was discussed by Ember and Otterbein (1991) and Mace and Pagel (1994), independence of specific cultural practices often is impossible to assess. Mace and Pagel advocated using cladistic methods to infer cultural independence, but as was pointed out by several respondents to them (1994, pp. 557–564), as well as by Mace and Pagel (1997, p. 305) themselves, it may not be appropriate to apply maximum parsimony techniques that were developed for investigating biological origins to infer cultural "phylogenies." Moreover, phylogenetic reconstructions of societal relationships (e.g., based on linguistic similarities: Ruhlen, 1987) do not necessarily yield inferences about independence of any specific cultural practice — like spice use. Finally, questions have been raised about the necessity of phylogenetic corrections when analyzing the current function of morphological traits (Ricklefs & Starck, 1996) and (especially) behaviors (Reeve & Sherman, 1993, 2001).

Otterbein (1994, p. 559) stated he "certainly would not cease using worldwide samples in comparative research because of the alleged difficulties that arise from the nonindependence of cases," and Hartung (1997, p. 347) pointed out that "Galton's problem . . . is like noise in a signal. It is more likely to obscure true relationships than to generate false ones." We agree and, therefore, included in our analyses all 36 countries for which traditional recipes were available (Table 1). The data indicated clearly that traditional cookbooks call for spices significantly less often in preparing vegetable- than meat-based dishes, regardless of whether recipes were considered individually or were lumped by major food items. In addition, even when vegetable dishes are seasoned, significantly fewer and less potent antimicrobial spices are used than in meat dishes.

Spice use in vegetable-based recipes increased with increasing ambient temperatures across countries, but much less dramatically than for meat-based recipes (Fig. 3). However, in these covariance analyses, the potential lack-of-independence problem becomes acute: Spice-use practices in the countries analyzed almost certainly are not equally independent, as required by this statistical technique (Sokal & Rohlf, 1995). This caveat does not apply to our nonparametric comparisons of spice use in vegetable- vs. meat-based recipes within all countries (e.g., Wilcoxon's signed rank tests). Indeed, these analyses show unequivocally that vegetable-based recipes are less spicy.

Results of intracountry comparisons of spice use (Table 1; Fig. 2) also are important. The consistent differences we found between vegetable- and meat-based dishes cannot be due to variations in spice-plant biogeography. Within-country differences must result from people's active choices to use or avoid certain spices — they cannot be ascribed to differences in availability of those spices.

Why do the marked and consistent differences between meat- and vegetable-based recipes exist? One possibility that will occur to most gastronomes is that vegetables have better, more "subtle" flavors to begin with, so spices are not needed to make them more appealing. This may indeed be the case. Whether or not it is, such a proximate (immediate cause) explanation does not address the ultimate (long-term cause) questions of why people find subtle flavors more appealing in vegetable- than meat-based dishes (Table 1; Fig. 2), why nearly every phytochemical is apparently tastier on meats than vegetables (Fig. 1), why subtle flavors are more acceptable in cold than hot climates (i.e., why spice use increases with temperature: Fig. 3) or, indeed, why foods that contain pungent plant products appeal to people at all. This reemphasizes the point, first made by Mayr (1961) and Tinbergen (1963), that answers to proximate and ultimate questions are complementary rather than mutually exclusive. Full understanding of spice use — or any behavior for that matter — requires explanations at both "levels of analysis" (Sherman, 1988; Sherman & Billing, 1999; Sherman & Flaxman, 2001).

Among the ultimate hypotheses for spice use (reviewed by Billing & Sherman, 1998; Rozin, 1990), three predict differences between vegetable- and meat-based dishes, particularly in hot climates: the antimicrobial, "cover-up," and "salt alternative" hypotheses. The cover-up hypothesis suggests that spices are useful because they disguise the foul smells and tastes of spoiled food (Govindarajan, 1985). In hot climates, there would more often be bad smells and tastes to cover up than in cool climates owing to more rapid spoilage, particularly of unrefrigerated meat products.

However, as a general explanation, the cover-up hypothesis is problematical because of the potential dangers of ingesting decayed foods. Although some foodborne microorganisms are harmless others are extremely dangerous, and there is no foolproof way to tell the difference from appearance or odor. Across the world, foodborne bacteria or their toxins debilitate millions of people annually and kill thousands (especially species of *Clostridium*, *Escherichia*, *Listeria, Salmonella*, *Staphylococcus*, and *Streptococcus*: Evans & Brachman, 1991; Jay, 1994; Todd, 1994, 1996). Even in the United States, where the food supply generally is considered to be "safe," foodborne illnesses afflict an estimated 80 million people per year (World Health Report, 1996) and 1 in 10 Americans experiences bacteria-related food poisoning annually (Hui et al., 1994). Moreover, new foodborne pathogens continually are evolving (e.g., Butler, 1996).

Even a poorly nourished person would be better off to err on the conservative side by passing up contaminated foods, especially meat products (Roberts, 1990; Sockett, 1995), if there were any chance they contained pathogenic bacteria or fungi that could be deadly to someone already in a weakened condition. It may even be that advantages of recognizing and avoiding spoiled and contaminated foods account for the sensitivity of our olfactory and gustatory systems to smells and tastes of decay. Because disguising tastes associated with spoilage potentially increases exposure to foodborne pathogens and their toxins, from an evolutionary perspective the "cover-up" hypothesis is seriously flawed.

Salt also has antimicrobial properties, and it has been used in food preparation and preservation for centuries (Multhauf, 1996). However, salt was not included in our analyses (Table 1) because it is a mineral, not a plant product (i.e., not a spice). The "salt alternative hypothesis" suggests that foods that are high in sodium are naturally better protected against bacteria and fungi than low-sodium foods. Therefore, spices should be used more sparingly on foods that are high in sodium. Under this alternative, if vegetables were especially high in sodium relative to meats, then spices might be used less frequently in vegetable recipes because further protection against foodborne microorganisms is unnecessary.

Considerable comparative information is available on the composition of foods (e.g., Chan, Brown, Lee, & Buss, 1995; Holland, Welch, et al., 1991; Holland, Unwin, & Buss, 1991). The data reveal that common vegetables such as carrots, potatoes, beans, and corn have sodium concentrations in the ranges of 1–40 mg/100 g, whereas meats such as beef, pork, chicken, and freshwater fish have sodium concentrations in the ranges of 60–100 mg/100 g (sodium concentrations in saltwater fish are even higher). Thus, there does seem to be a difference in sodium concentrations between vegetables and meats, but it is in the opposite direction to that predicted by the salt alternative hypothesis. Apparently, vegetables are not spiced less than meats because they are naturally saltier. Overall, the data are thus more consistent with the antimicrobial hypothesis than with the two most likely alternatives to it.

A further question is how and when people began using spices. Although no one knows this, we can infer that food spoilage and foodborne pathogens would have become problematical for our ancestors when they began killing wild game that was too large to be consumed immediately or scavenging large carcasses. This occurred as long as 2.5 Ma (i.e., in the Pliocene) among hominids living in Africa (de Heinzelin et al., 1999; Monahan, 1996), and it certainly occurred at least 100 ka ago among Neanderthals living in Europe and the Middle East (Richards et al., 2000).

We speculate that people initially used pungent plant materials either because their flavors were appealing (e.g., cinnamon, basil) or they caused pleasurable psychological sensations. For example, chili peppers can trigger intense feelings of pleasure and an opponent-endorphin response (Rozin, 1990). In addition, people probably felt healthier for some time after eating spice plants. Not only would they have experienced fewer foodborne illnesses and less food poisoning, but they might also have benefited from other therapeutic effects such as enhanced digestion, better metabolism, or lowered blood pressure (Johns, 1990; Lin, 1994).

Once established, practices associated with use of particular pungent plant materials would have been easily transmitted culturally, by word of mouth and example. "Horizontal" transmission would occur through observation and imitation of the food-preparation habits of healthier families by neighbors, and "vertical" transmission would occur if parents that used appropriate spices reared more healthy offspring and taught them familial spice-use traditions. It also is possible that people living in areas where certain spices were used regularly evolved physiologically heightened abilities to taste those phytochemicals. There is genetic variation both in numbers of taste receptors that respond to particular spices and in their sensitivity (Drewnowski & Rock, 1995), but the biogeography of such variations relative to spice use has not been explored.

Eventually, any hominid group would be afflicted by new foodborne bacteria or fungi due either to microbial dispersal or the evolution of resistance to commonly used spices among indigenous microorganisms. Individuals eating foods contaminated by these microbes would become ill. When humans, like many other creatures, eat something that makes them nauseous, they tend to avoid that taste subsequently (Milgram, Krames, & Alloway, 1977). The adaptive value of such "taste-aversion learning" is obvious (Letarte, Dube, & Troche, 1997). Adding a different spice to a food that caused such an illness could both change its flavor enough to make it palatable again and kill the microorganism(s) that caused the illness in the first place, rendering it safe for consumption. By this process, food aversions would more often be associated with unspiced (and unsafe) foods, whereas food likings would be associated with spicy dishes, especially meat products in hot climates where unrefrigerated foods spoil rapidly. Over time, the number and identity of spices in each meat or vegetable recipe would change due to iteration of this process, i.e., sequential changes in taste, associated with inhibiting different bacteria and fungi. From this perspective, traditional cookbooks are far more than instruction manuals: They represent a record of humans' culinary responses in a never-ending coevolutionary race against foodborne microorganisms.

In conclusion, we discovered that traditional vegetable-based recipes call for less seasoning than meat-based recipes. We believe that this is because cooked vegetables and leftovers were poorer media than meats for growth of microorganisms when traditional recipes were developed (i.e., prior to widespread use of refrigeration and chemical preservatives and artificial selection to reduce secondary compounds in food plants). In turn, this minimized the need to accept the physiological risks and financial costs associated with adding numerous antimicrobial preservatives — i.e., spices — to vegetable dishes. A Darwinian view of gastronomy thus suggests that there is a functional reason for the substantial differences in spiciness of meat- and vegetable-based recipes that exists throughout the world.

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