VOLUME 73, NO. 1 MARCH 1998

THE QUARTERLY REVIEW
of BIOLOGY

ANTIMICROBIAL FUNCTIONS OF SPICES: WHY SOME LIKE IT HOT

JENNIFER BILLING* AND PAUL W. SHERMAN

Section of Neurobiology and Behavior, Cornell University
Ithaca, NY 14853 USA

ABSTRACT

Although spices have been important for centuries in food preparation throughout the world, patterns of spice use differ considerably among cultures and countries. What factors underlie these differences? Why are spices used at all? To investigate these questions, we quantified the frequency of use of 43 spices in the meat-based cuisines of the 36 countries for which we could locate traditional cookbooks. A total of 4578 recipes from 93 cookbooks was analysed. We also compiled information on the temperature and precipitation in each country, the ranges of spice plants, and the antibacterial properties of each spice. These data were used to investigate the hypothesis that spices inhibit or kill food-spoilage microorganisms. In support of this is the fact that spice plant secondary compounds are powerful antimicrobial (i.e., antibacterial and antifungal) agents. As mean annual temperatures (an indicator of relative spoilage rates of unrefrigerated foods) increased, the proportion of recipes containing spices, number of spices per recipe, total number of spices used, and use of the most potent antibacterial spices all increased, both within and among countries. Likewise, the estimated fraction of bacterial species inhibited per recipe in each country was positively correlated with annual temperature.

Several alternative hypotheses were considered—that spices provide macronutrients, disguise the taste and smell of spoiled foods, or increase perspiration and thus evaporative cooling; it also is conceivable that spice use provides no benefits. However, none of these four alternatives was well supported by our data. The proximate reason spices are used obviously is to enhance food palatability. But the ultimate reason is most likely that spices help cleanse foods of pathogens and thereby contribute to the health, longevity and reproductive success of people who find their flavors enjoyable.

---

*Present address: 191 Quail Hollow Lane, East Amherst, NY 14051 USA.

The Quarterly Review of Biology, March 1998, Vol. 73, No. 1

0033-5770/98/7301-0001$2.00

INTRODUCTION

AROMATIC PLANT materials have been used in food preparation for thousands of years (Parry 1953; Govindarajan 1985). Ancient Vedic texts and the Ayurvedic texts of Susruta and Caraca (Johri and Zutshi 1992) indicate systematic use of spices in regions where the plants grew naturally (e.g., Hindustan and the Spice Islands). When Alarich, leader of the Goths, besieged Rome in 408 AD, he demanded as ransom 5000 lbs. of gold and 3000 lbs. of *pepper* (Scheiper 1993). In the Middle Ages and after, hazardous voyages were undertaken by famous seafarers, such as Marco Polo from Italy; Pedro Cabral, Vasco da Gama, and Ferdinand Magellan from Portugal; Christopher Columbus and Hernando Cortes from Spain; and by numerous sailors from France, England and the Netherlands in order 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 to control them precipitated several wars (Govindarajan 1985).

What are spices? A spice may be defined as "any dried, fragrant, aromatic, or pungent vegetable or plant substance, in the whole, broken, or ground form, that contributes flavor, whose primary function in food is seasoning rather than nutrition, and that may contribute relish or piquancy to foods or beverages" (Farrell 1990:17). Sources of spices include "1) aromatic lichens; 2) any part of a tree or woody shrub or vine used for flavoring; 3) roots, flowers, seeds, or fruits of herbaceous plants such as saffron and ginger, the leaves of which are not used for flavoring; and 4) extracts or essential oils of any of these plants" (Morton 1976:5). Thus, "spice" is a culinary rather than a botanical term.

Culinary texts (e.g., Farrell 1990; Tainter and Grenis 1993) generally distinguish between seasonings (spices used in food preparation) and condiments (spices added after food is served), but they do not distinguish between herbs and spices. In their book, Loewenfeld and Back (1974) define herbs botanically as plants "more or less soft or succulent, mostly grown from seeds and not developing woody, persistent tissue" and state that "herbs are usually used fresh and are considered to be a better flavouring in their fresh state" (p 17).

But why are spices used? The most obvious answer is that they enhance the flavor and palatability of food, but this is only a proximate explanation; it does not address the ultimate, evolutionary question of why people find foods tastier when they are flavored with plant secondary compounds. Answers to such proximate and ultimate questions are complementary, and full understanding requires explanations at both levels of analysis (Sherman 1988; Alcock and Sherman 1994). In this paper we explore ultimate-level questions by focusing on the hypothesis that adding spices to foods is beneficial because spices contain substances that inhibit or kill food-spoilage microorganisms. It is well known that some spices have antibacterial and antioxidant properties (Shelef 1984; Deans and Ritchie 1987; Zaika 1988; Beuchat and Golden 1989; Beuchat 1994; Nakatani 1994). Moreover, spices have long been used to preserve food in traditional societies (Meyer 1918:186–187; Rivers and Hill 1971; Nkanga and Uraih 1981; Rusul et al. 1997) and industrial countries (Hoffman and Evans 1911; Pruthi 1980; Dillon and Board 1994; Ziauddin et al. 1996). For centuries, spices also were used in embalming to prevent the decay of corpses (Parry 1953). However, the idea that spices serve an antimicrobial function has never been systematically investigated.

Here we evaluate four critical predictions of the antimicrobial hypothesis: (i) spices should kill or inhibit food-spoilage microorganisms; (ii) spice use should be heaviest in hot climates, where (unrefrigerated) foods spoil most rapidly; (iii) spices with the most potent antimicrobial properties should be favored in areas where foods spoil most quickly; and (iv) spices used in a region should be especially potent against local pathogens. We also investigated several alternative benefits of spice use, including that of providing macronutrients, disguising the smell or taste of spoiled foods, and increasing perspiration (thereby enhancing evaporative cooling). Finally, we considered the "null" hypothesis that spice use per se confers no benefits, and that people simply use whichever aromatic plants are available locally to flavor their food.

TABLE 1

Countries included in this study, climatic variables, numbers of recipes surveyed, and traditional cookbooks consulted for meat-based recipes

Country	Mean Temperature (°C)	Mean Precipitation (cm)	Number of Recipes (n)	Cookbooks
Thailand	27.6	149.6	118	Chaslin and Canungmai 1987; Vista 1978
Philippines	27.0	193.5	118	Alejandro 1982; Claudio 1977
India	26.9	117.6	91	Sahni 1980; Muthachen 1969; Pandya 1980; Patil 1988
Malaysia	26.9	235.0	60	Harben 1983; Fernandez 1985
Indonesia	26.8	204.7	120	Owen 1976; DeWit and Borghese 1973
Nigeria	26.5	139.2	82	Anthonio and Isoun 1982; Hafner 1993; Ritzberg 1993
Ghana	25.9	106.3	95	Dede 1969; Ritzberg 1993; Nyaho et al. 1970
Vietnam	24.6	170.2	84	Duong and Kiesel 1991; Ngo and Zimmerman 1979
Brazil	23.9	177.8	132	Moliterno 1963; De Andrade 1965
Mexico	23.1	95.3	123	Kennedy 1978; Blue 1977
Kenya	22.1	108.0	73	Hyder 1976; Gardner 1993; Ritzberg 1993
Ethiopia	21.1	88.9	56	Mesfin 1987; Ritzberg 1993
Lebanon	20.6	80.5	98	Salloum 1992; Farah 1979
Israel	19.1	53.8	145	Bar-David 1964; Nahoum 1971
Australia	18.6	91.9	64	McKenzie and Allen 1980; Cameron et al. 1980
Morocco	18.3	25.4	104	Day 1975; Carrier 1987
South Africa	17.2	48.1	108	Higham 1950; De Villiers 1961
Greece	16.7	60.7	118	Kremezi 1993; Mark 1974; Barron 1991
Iran	16.7	20.3	85	Hekmat 1994; Shaida 1992; Batmanglij 1992
Portugal	15.0	77.2	84	Sarvis 1967; Anderson 1986
Japan	14.3	144.5	103	Chen 1988; Martin and Martin 1970
Italy	14.0	80.5	86	Bugialli 1992; De' Medici 1990
Korea	12.1	121.4	81	Morris 1945; Millon and Millon 1991; Shim 1984
France	12.1	75.4	216	Willan 1981; Escudier and Fuller 1968
Hungary	10.3	56.3	80	Lang 1971; Weiss and Buchan 1979
Ireland	9.6	93.5	90	Sheridan 1965; Armstrong 1986
England	8.8	72.1	223	Boyd 1976; Grigson 1985
Germany	8.8	67.3	169	Schuler 1955; Adam 1967
Austria	8.8	85.6	188	Mayer-Browne 1961; Langseth-Christensen 1959
Denmark	8.3	62.2	87	Hazelton 1964; Jensen 1962
Poland	7.8	52.3	141	Zeranski 1968; Czerny 1975
Sweden	5.4	53.8	134	Berg 1963; Jakobsson 1989
Finland	3.0	57.4	62	Benton 1960; Viherjuuri et al. 1974
Norway	2.8	96.0	77	Sverdrup 1962; Holmboe 1957
		Countries with Regional Differences		
United States				
Northern	8.6	92.9	453	Cleveland 1952; White 1993; Ferguson 1989; *Flavor of the South* 1989; Olivet Episcopal 1960; Wilson 1990; Brown 1987; *Southwest Cooking* 1990; Karousos et al. 1993
Southern	17.8	90.2		
China				
Northeast	13.4	85.3	430	Hom 1990; Schrecker and Schrecker 1976; Simoons 1991; Lo 1971, 1979; Lee and Lee 1976; Low 1982; Chang et al. 1982; Mei 1978; Kan and Leong 1963
Southwest	19.4	132.7		

To evaluate these hypotheses, we gathered data from several extensive and diverse literatures. Our approach was, of necessity, correlational rather than experimental, and we inferred but did not directly measure how spice use affects the fitness of individuals. This represents the "forward method" for studying human social evolution (Sherman and Reeve 1997). Our results suggest that spice use is beneficial, and yield intriguing insights into the question of why cuisines of different countries vary so much in spiciness.

METHODS

SELECTION OF CUISINES

We quantified the spices used in the cuisines of countries for which we could locate >50, and preferably >100, meat-based recipes from at least two traditional cookbooks. A meat-based recipe is one in which at least one-third of its total volume or weight consists of red meat, poultry, pork, veal or seafood; soups, stews, roasts and casseroles are included. We focused on meat-based recipes because unrefrigerated meats spoil faster and are associated with foodborne disease outbreaks more often than vegetables (Bryan 1988; Roberts 1990; Todd 1994, 1996; Sockett 1995), so any relationship between microbial contamination and spice use should be evident in meat-based recipes. And since meat-based recipes typically are far more common than vegetarian recipes in traditional cookbooks, we were able to obtain adequate sample sizes for statistical analyses.

We considered a cookbook "traditional" when authors stated that their purpose was to record a 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 experimental and modern cookbooks, and those written primarily for American audiences (as indicated in the title or preface). Of course, cookbooks were selected without regard to the frequency with which their recipes called for spices. To minimize the possible effects of authors' biases (e.g., preferences for spicy or bland recipes), we consulted ≥2 cookbooks for each country. In fact, cookbooks from the same country always deviated <5% in the total number of different spices used and the average number of spices per recipe. If two books together provided <50 meat-based recipes, a third (or fourth, etc.) book was consulted to increase the sample size. Based on these criteria, we located 93 traditional cookbooks from 36 countries (Table 1), representing every continent and 16 of the world's 19 "language families" (Ruhlen 1987).

SELECTION OF SPICES

We considered all spices ($n=43$) used in meat-based recipes, regardless of the quantity or form (dried, powdered or fresh) called for (Table 2). For analyses, we grouped spices whose essential oils contain the same chemical components (Farrell 1990). Thus, "capsicum" includes all capsaicin-containing peppers (chilies, genus *Capsicum*) except paprika and green peppers; the latter two have undergone artificial selection to contain minimal capsaicin (Wilkins 1994). "Onion" includes leeks, chives, shallots and onions, and "pepper" includes white and black pepper (although nearly every recipe called for black pepper only).

Onions and chilies presented a special problem because they can be used either as main dishes or only as spices. Since they always add flavor (propyl disulfides and capsaicins, respectively) to recipes, we considered them to be spices, regardless of the quantities called for. Salt was not included in our analyses because it is not a plant product and therefore, technically, not a spice. However, as will be seen, reasons for salting and spicing foods probably are similar.

ANTIBACTERIAL PROPERTIES OF SPICES

Bacteria have been more commonly incriminated in food poisoning and foodborne disease outbreaks than yeasts and fungi (e.g., Varnam and Evans 1991; Todd 1994, 1996). Therefore, we focused on the possible antibacterial properties of spices. We searched the literature for information on foodborne bacteria that have been experimentally challenged with each spice, and the "inhibitory" ability of each spice—whether the spice killed the bacterium outright or slowed its growth (Appendix A). We located original sources by consulting review articles (e.g., Deans and Ritchie 1987; Beuchat and Golden 1989; Beuchat

TABLE 2

Spice plants and their native and domesticated ranges in the 34 "nonregional" countries in this study (i.e., all except China and the United States)

SPICE	FAMILY	SPECIES	India	Iran	Vietnam	Malaysia	Indonesia	Thailand	Philippines	Korea	Japan	Morocco	Lebanon	Australia	Israel	Greece	Norway	Ireland	Denmark	Germany	Finland	Sweden	Poland	England	Portugal	Italy	Austria	Hungary	France	Brazil	Mexico	South Africa	Ghana	Nigeria	Kenya	Ethiopia
ALLSPICE	Myrtaceae	*Pimenta dioica*	X		X	X	X	X	X																					X			X	X		
ANISE	Umbelliferae	*Pimpinella anisum*	X	X	X							X	X		X	X				X			X		X	X	X	X	X		X					
BASIL	Labiatae	*Ocimum basilicum*	X		X	X	X	X	X	X	X	X	X		X	X									X	X	X	X	X			X	X	X	X	X
BAY	Lauraceae	*Laurus nobilis*		X								X	X		X	X		X	X	X			X	X	X	X			X		X					
CAPERS	Caparidaceae	*Capparis spinosa*	X									X	X		X	X	X		X	X	X	X	X		X	X			X							
CARAWAY	Umbelliferae	*Carum carvi*										X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X							
CARDAMOM	Zingiberaceae	*Elletaria cardamomum*	X		X	X	X	X	X			X	X		X	X									X	X					X		X	X		
CELERY	Umbelliferae	*Apium graveolens*														X	X	X	X	X	X	X	X	X	X	X	X	X	X			X				X
CHILI PEPPER	Solanaceae	*Capsicum frutescens*	X	X	X	X	X	X	X	X	X	X	X	X	X	X									X	X	X	X		X	X		X	X		
CINNAMON	Lauraceae	*Cinnamomum zeylanicum*	X		X	X	X	X	X																					X			X	X		
CLOVES	Myrtaceae	*Syzygium aromaticum*	X		X	X	X	X	X																					X			X	X		
CORIANDER	Umbelliferae	*Coriandrum sativum*	X	X	X	X	X	X	X	X	X	X	X		X	X									X	X	X	X	X	X			X	X		
CUMIN	Umbelliferae	*Cuminum cyminum*	X	X								X	X		X	X			X	X			X		X	X			X							
DILL	Umbelliferae	*Anethum graveolens*	X									X	X		X	X									X	X			X							
FENNEL	Umbelliferae	*Foeniculum vulgare*										X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X				X
FENUGREEK	Leguminosae	*Trigonella foenum graecum*	X									X																								
GARLIC	Liliaceae	*Allium sativum*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
GINGER	Zingiberaceae	*Zingiber officinale*	X		X	X	X	X	X	X	X																			X			X	X		
HORSERADISH	Cruciferae	*Armoracia lapathifolia*	X										X		X	X									X	X	X	X	X	X						
JUNIPER	Cupressaceae	*Juniperus communis*														X	X	X	X	X	X	X	X	X		X	X	X	X							
LAOS	Zingiberaceae	*Alpinea galanga*	X		X	X	X	X	X																											
LEMON	Rutaceae	*Citrus limon*	X	X								X	X	X	X	X									X	X				X		X				
LEMONGRASS	Gramineae	*Cymbopogon citratus*	X		X	X	X	X	X	X	X																			X			X	X		
LIME	Rutaceae	*Citrus aurantifolia*	X		X	X	X	X	X																					X	X		X	X		
MARJORAM	Labiatae	*Origanum majorana*										X	X		X	X			X	X			X		X	X	X	X	X							
MINT	Labiatae	*Mentha arvensis*		X						X	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X
MUSTARD	Cruciferae	*Brassica juncea*	X	X						X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X				X
NUTMEG	Myristicaceae	*Myristica fragrans*	X		X	X	X	X	X																					X			X	X		
ONION	Liliaceae	*Allium cepa*	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
OREGANO	Labiatae	*Origanum vulgare*		X								X	X		X	X			X	X			X		X	X			X							
PAPRIKA	Solanaceae	*Capsicum annum*	X	X	X	X	X	X	X	X	X	X	X	X	X	X									X	X	X	X		X	X		X	X		
PARSLEY	Umbelliferae	*Petroselinum crispum*										X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	X						X	
PEPPER	Piperaceae	*Piper nigrum*	X		X	X	X	X	X																					X			X	X		
ROSEMARY	Labiatae	*Rosmarinus officinalis*										X	X		X	X		X	X	X			X	X	X	X			X							
SAFFRON	Iridaceae	*Crocus sativus*		X								X	X		X		X								X	X			X							
SAGE	Labiatae	*Salvia officinalis*										X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X							
SAVORY	Labiatae	*Satureja hortensis*		X								X	X		X	X									X	X			X						X	
SESAME	Pedaliaceae	*Sesamum indicum*	X		X	X	X	X	X	X	X																			X	X		X	X	X	
SWEET PEPPER	Solanaceae	*Capsicum grossum*	X	X	X	X	X	X	X	X	X	X	X	X	X	X									X	X	X	X		X	X		X	X	X	
TAMARIND	Leguminosae	*Tamarindus indica*	X		X	X	X	X	X			X	X	X	X															X	X		X	X		
TARRAGON	Compositeae	*Artemisia dracunculus*															X	X	X	X	X	X	X	X			X	X	X							
THYME	Labiatae	*Thymus vulgaris*										X	X		X	X	X		X	X	X	X	X		X	X			X						X	
TURMERIC	Zingiberaceae	*Curcuma longa*	X		X	X	X	X	X	X	X																						X	X		

1994) and on-line databases (e.g., Agricola, Biosis, FSTA, and Medline). Most studies evaluated spices as food preservatives, in attempts to identify minimum concentrations necessary to suppress bacterial growth without adversely affecting flavor.

We included inhibition studies regardless of whether they tested the spice in its powdered form or as purified active ingredients (e.g., volatile oils or oleoresins). We only included those studies that identified bacteria to species, but we did not try to distinguish "strains" within species. We also did not differentiate among studies that tested different colony sizes of bacteria. Not all bacteria have been studied for every spice, and some spices were tested on many more bacteria than others.

Studies sometimes reached dissimilar conclusions about whether a spice inhibited a particular bacterium. We resolved discrepancies that resulted from differing definitions of inhibition with our "inclusive" definition of inhibition as the mortality or retardation of growth. Concentrations of spices tested varied considerably (e.g., 100–100,000 ppm), and in some cases different spice concentrations led to different conclusions. If a study reporting inhibition for a particular spice tested a higher concentration than the study or studies reporting no inhibition, we assumed the spice was indeed inhibitory. However, if studies using the same concentration reported contradictory results, or if the study reporting inhibition used a lower concentration, we eliminated the bacterium from consideration relative to that spice. Studies that did not report the concentrations tested were not included.

We wanted to quantify the proportion of local food-spoilage bacteria that would be inhibited by recipes from each country. Unfortunately, however, no comprehensive list of indigenous bacteria exists for any country, so we had to estimate this degree of inhibition. First, we listed the 30 species of bacteria that have been experimentally challenged with the greatest number of spices, regardless of how frequently they were inhibited (Appendix B). All 30 were challenged with >10 spices, and most with ≥ 20 ($21/30 = 70.0\%$); the mean number of spices used to challenge each bacterium was 18.2 ± 3.6 (sd). Next, we randomly picked 30 recipes from the cookbooks for each country (by numbering recipes consecutively and consulting a random numbers table), and tallied how many of our 30 target bacteria were inhibited by at least one spice in each recipe. Each set of results for the 30 recipes was averaged, yielding an estimate of the mean number of bacterial species inhibited per recipe per country. Although this estimate is crude, it is unbiased, and probably representative because most of our 30 target bacteria are distributed worldwide.

CLIMATE DETERMINATIONS

The climate of each country was determined by averaging monthly temperature and precipitation data from each major city listed in *The Weather Handbook* (Conway and Liston 1990). Some countries include regions that differ greatly in latitude and altitude, resulting in major differences in mean annual temperatures. Potentially this presented us with opportunities to assess variations in spice use among different climatic regions. Unfortunately, among these countries, we could locate regional cookbooks only for China and the United States. We analysed the climate of these two countries in the following manner.

Although Chinese cuisine often is subdivided into four geographical regions (Simoons 1991), traditional cookbooks were available only for northeastern and southwestern China (Table 1). 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 (Simoons 1991). We calculated the mean annual temperature and precipitation for the cities of Lanzhou, Beijing, Tianjin, Shenyang and Shanghai in north and east China, and Kunming, Changsha, Hankow, Chungking, Canton and Nanning in the south and west, using data in Conway and Liston (1990) and Bair (1992).

Traditional cookbooks also were available for the northern and southern United States (Table 1). We characterized these climates using Bair's (1992) data on the cities of Buffalo, New York, Pittsburgh, Portland, San Francisco, Sault Ste. Marie, Washington (DC), Fairbanks and Juneau in the north, and Albuquerque, Asheville, Atlanta, Austin, Birmingham, Brownsville, El Paso, Jacksonville, Los Angeles, Louisville, Miami, Nashville, New Orleans and Phoenix in the south.

STATISTICAL ANALYSES

Cross-cultural analyses always confront "Galton's problem" (Hartung 1982) of selecting societies for comparison that adequately represent a range of cultural variation but minimizing cases in which similarities are due to recent common derivation or diffusion. Analysing cross-cultural data also is problematic and controversial. Of course, independence of specific cultural practices is statistically desirable but, as discussed by Ember and Otterbein (1991) and Mace and Pagel (1994), independence often is impossible to assess.

In an attempt to increase the independence of our data, we initially searched for cookbooks from cultures or tribes listed in Murdock's (1967) Standard Cross-Cultural Sample. Unfortunately, we were largely unsuccessful in matching Murdock's sample. Therefore we sought traditional cookbooks from as broad a range of countries as possible. We discovered that 28 of the 36 countries for which we found appropriate cookbooks belong to different "tribal clusters" according to Murdock (also Murdock and White 1969). To improve independence, we tried omitting all except one of the countries that certainly or probably belong to each cluster, but this severely reduced our sample size and the range of variation. Moreover, the advisability of arbitrarily omitting countries is questionable when their degrees of independence for a specific cultural practice are unknown (Ember and Otterbein 1991).

The use of cladistic methods to infer independence of cultures has been suggested, but as pointed out by several respondents to Mace and Pagel (1994:557–564) as well as Mace and Pagel, themselves (1997:305), it may not be appropriate to apply maximum parsimony techniques that were developed for investigating biological origins to inferring cultural "phylogenies." Moreover, the recent report by Ricklefs and Starck (1996) that comparative analyses of physiological and morphological traits (of birds) based on phylogenetic reconstructions yielded similar conclusions to those based on correlation of trait values of individual species, regardless of relatedness, raises the question of when controlling for phylogenetic independence is essential (Weathers and Siegel 1995).

Nonetheless, we attempted to use Mace and Pagel's (1994, 1997) phylogenetic methods (based on linguistic similarities) to select countries for inclusion in our analyses. However, considering only countries that belong, unambiguously, to different "linguistic families" (Ruhlen 1987) cut our sample size to the point that statistical analyses were meaningless. Moreover, phylogenetic reconstructions of societal relationships based on linguistic similarities do not necessarily yield inferences about the independence of spice-use patterns.

Otterbein (1994:559) stated he "certainly would not cease using worldwide samples in comparative research because of the alleged difficulties that arise from the nonindependence of cases." Moreover, as Hartung (1997:347) pointed out, "Galton's problem . . . is like noise in a signal. It is more likely to obscure true relationships than to generate false ones." We therefore included in our analyses all 36 countries for which we obtained traditional recipes (Table 1), with the caveat that some countries are more nearly "independent" than others.

We used standard nonparametric statistical procedures, primarily Pearson product-moment correlations (*r*), partial correlations, and chi-square analyses (Minitab Release 10.5 Xtra). When multiple tests within a hypothesis were performed, *P* values were adjusted with Bonferroni corrections (Moore and McCabe 1993) to minimize Type 1 errors (Rice 1989). Proportional data were appropriately transformed (arc sine square root) for analyses.

Results

GENERAL PATTERNS OF SPICE USE

Of the 4578 meat-based recipes we analysed, 4241 (93%) called for at least one spice. The mean number of spices per recipe was 3.9 (±1.7 sd). In ten countries (28%), namely Ethiopia, Kenya, Greece, India, Indonesia, Iran, Malaysia, Morocco, Nigeria and Thailand, every meat-based recipe called for at least one spice. By contrast, in Finland and Norway, respectively, 19 of 62 (31%) and 25

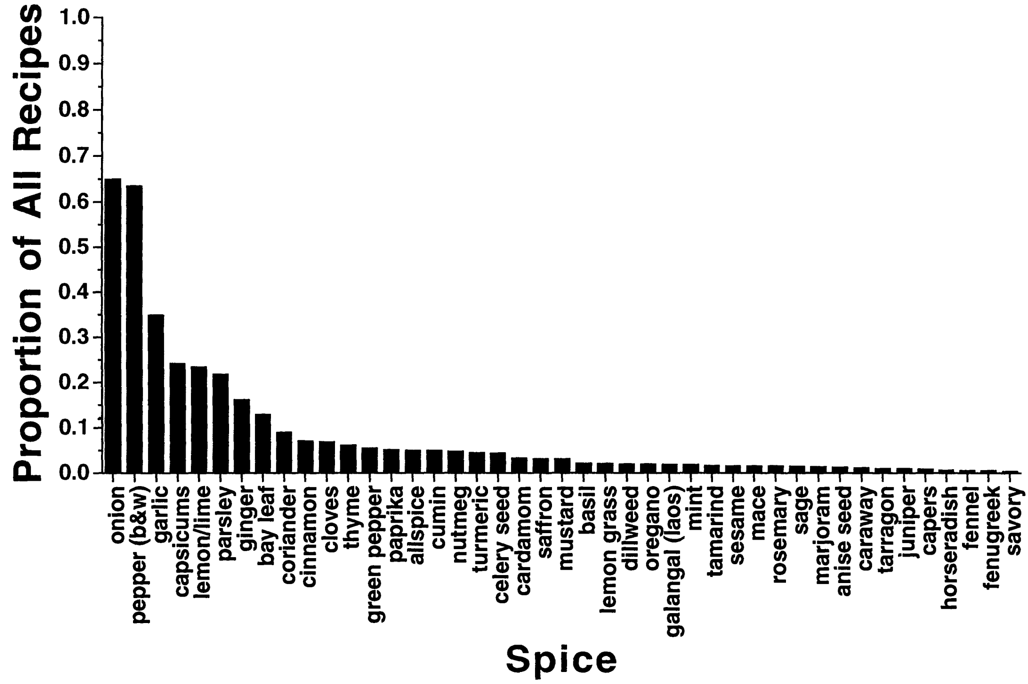


FIGURE 1. PROPORTIONS OF 4578 MEAT-BASED RECIPES SURVEYED THAT CALLED FOR EACH OF 43 SPICES. Data are from 93 traditional cookbooks from 36 countries (see Table 1).

of 77 meat-based recipes (33%) did not call for any spices.

Among various cuisines, individual spices are not used equally often (Figure 1). Onion and pepper are called for in well over half of all meat-based recipes (65% and 63%, respectively). Other frequently used spices are garlic (35%), capsicums (24%), lemon and lime juice (23%), parsley (22%), ginger (16%), and bay leaf (13%). The vast majority of spices are called for in <10% (35/43 spices = 81%) or in <5% of all recipes (29/43 = 67%).

CLIMATIC VARIABLES

Temperature

The countries in our sample represent a wide spectrum of climates (Table 1), with mean annual temperatures ranging from 2.8° C (Norway) to 27.6° C (Thailand). Among the 34 nonregional countries (i.e., those without regional cookbooks), patterns of spice use also differ considerably, as illustrated in Figure 2 for representative countries with "very hot" (mean annual temperature >26° C), "temperate" (10–21° C), and "cold" (<10° C) climates. In general, countries with hot climates use numerous spices, many of which are commonly called for (i.e., in >40% of recipes), whereas countries with cooler climates use fewer spices, most of which are rarely called for (in <5% of recipes). Histograms for hotter countries approximate normal distributions while those for cooler countries approximate negative exponentials. We quantified this variation by calculating kurtosis (degree of peakedness) and skew (degree of asymmetry) for all 34 frequency-of-use histograms (Hinkle et al. 1988). Figure 3 shows that both measures decrease significantly with increasing mean annual temperatures (kurtosis: $r=-0.542$, df=32, $P=0.001$; skew: $r=-0.512$, $P=0.002$).

Spice contents of recipes also vary with climate. Among the 34 nonregional countries, there are significant positive correlations between mean annual temperatures and proportions of recipes that call for at least one spice ($r=0.740$, df=32, $P<0.001$; Figure 4a), and mean annual temperatures and mean numbers of spices per recipe (r=0.572, P=0.002; Figure 4c); the correlation between temperatures and numbers of different spices used in each country also is positive, but not significant (r=0.216, P=0.286; Figure 4e). Proportions of all spices used in each country that are called for "frequently" (i.e., in >40% of recipes) are positively correlated with mean annual temperatures (r=0.426, P=0.012), whereas proportions of spices used in each country that are called for "infrequently" (in <5% of recipes) are inversely correlated with temperatures (r=−0.450, P=0.010).

The use of many individual spices varies with the climate. For ten spices there are positive correlations between mean annual temperatures and frequencies of use (percent of recipes per country that called for the spice). As shown in Figure 5, this group includes capsicums (r=0.757, df=32, P<0.001), garlic (r=0.635, P<0.001), and onion (r=0.652, P<0.001), as well as anise (r=0.377, P=0.028), cinnamon (r=0.347, P=0.044), coriander (r=0.582, P=0.001), cumin (r=0.435, P=0.010), ginger (r=0.462, P=0.006), lemongrass (r=0.478, P=0.004), and turmeric (r=0.393, P=0.021). Among these, cinnamon, coriander, cumin and ginger are used primarily in countries with mean temperatures >16° C, and anise, lemongrass and turmeric are used almost exclusively in very hot countries (⩾26° C). For two spices, dill (r=−0.365, P=0.034) and parsley (r=−0.365, P=0.034), there are negative correlations between mean annual temperatures and frequencies of use.

Relationships between mean temperature and frequency of use of basil, bay, cardamom, celery, cloves, green peppers, mint, nutmeg, saffron and oregano all are positive but nonsignificant (all P>0.05), and relationships between temperature and frequency of use of allspice, bay, celery, marjoram, mustard, paprika, rosemary, sage and thyme are negative but nonsignificant. The other 14 spices in our sample are used too infrequently (in too few countries or too few recipes) to permit statistical analyses.

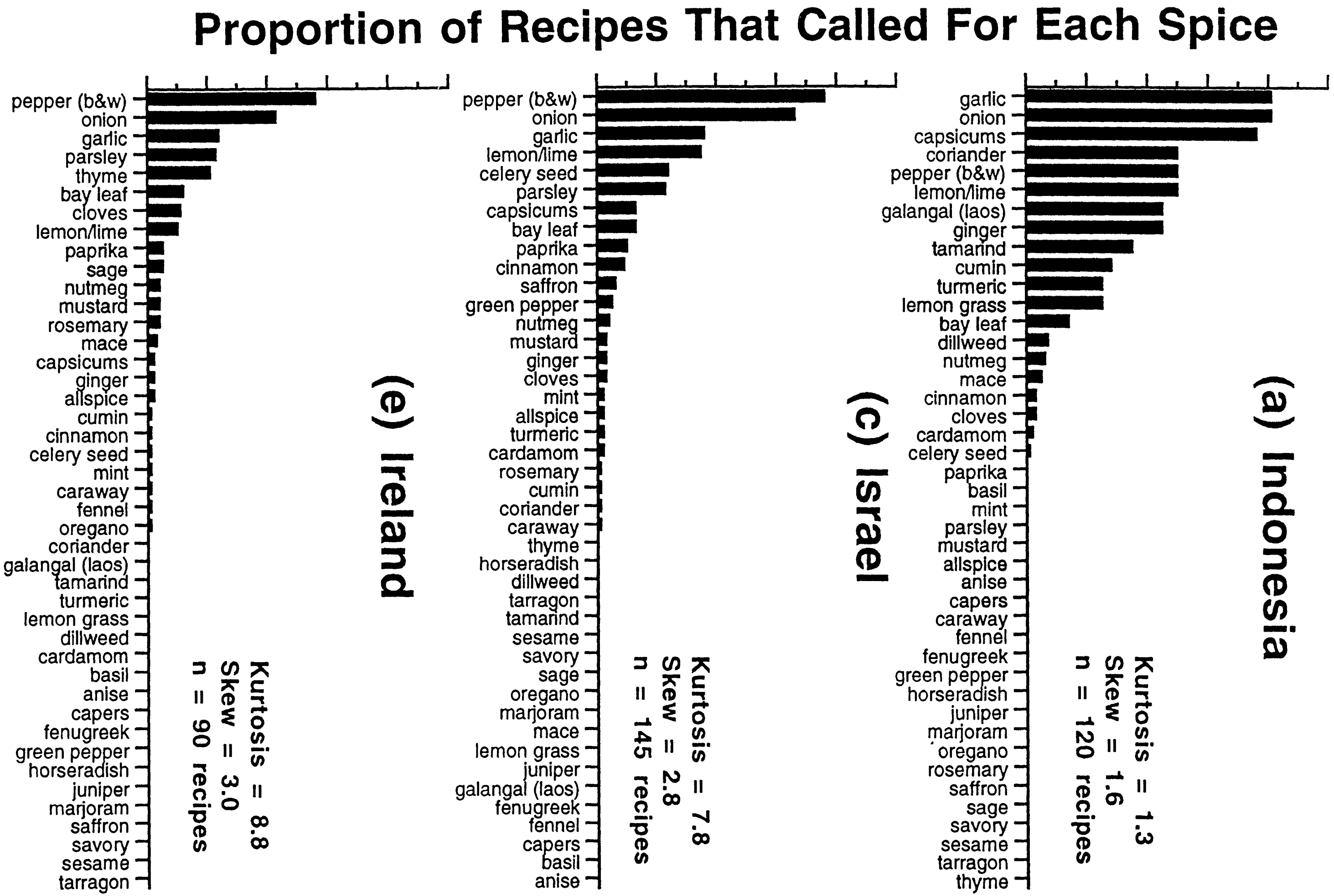
Precipitation

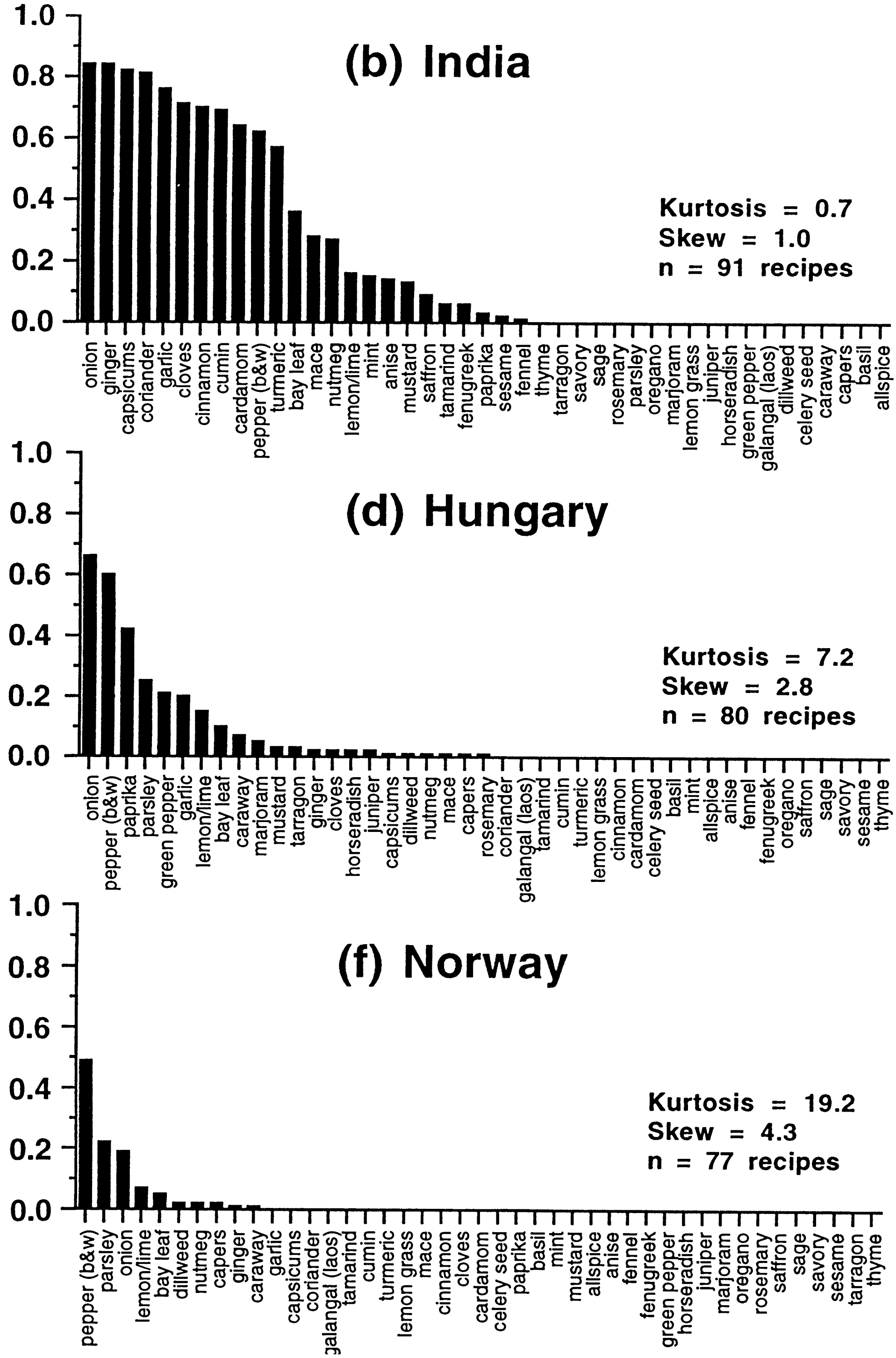
Mean annual precipitation among countries ranges from 20.3 cm (Iran) to 235 cm (Malaysia; Table 1). For the 34 nonregional countries, frequency-of-use histograms do not vary systematically with annual precipitation, and there are no significant correlations between precipitation and skew (r=−0.316, df=32, P=0.069) or kurtosis (r=−0.337, P=0.061). There also are no correlations (all P>0.10) between mean annual precipitation and proportions of recipes that call for at least one spice (r=0.235; Figure 4b), mean numbers of spices per recipe (r=0.220; Figure 4d), numbers of different spices used in each country (r=0.129; Figure 4f), or proportions of spices used in each country that are called for in >40% of recipes (r=0.191) or in <5% of recipes (r=−0.304). There are no significant correlations between frequencies of use of any spice and mean annual precipitation.

We conducted partial correlation analyses to see if precipitation affects spice-use patterns when temperature is controlled statistically. Holding mean annual temperatures constant, there still are no significant partial correlations (all P>0.05) between mean annual precipitation and numbers of different spices used in each country (partial r=0.229, df=31), proportions of recipes that call for at least one spice (partial r=0.328), mean numbers of spices per recipe (partial r=0.204), or proportions of spices used in each country that are called for in >40% of recipes (partial r=0.061) or in <5% of recipes (partial r=−0.049). There also are no significant partial correlations between frequencies of use of any spice and precipitation, when temperature effects are controlled.

FIGURE 2. FREQUENCY-OF-USE HISTOGRAMS SHOWING PROPORTIONS OF MEAT-BASED RECIPES THAT CALLED FOR EACH SPICE IN SELECTED COUNTRIES WITH DIFFERENT MEAN ANNUAL TEMPERATURES.

Indonesia and India represent countries with "hot" climates (mean annual temperature >26° C), Israel and Hungary represent more "temperate" climates (10–21° C), and Ireland and Norway represent "cold" climates (<10° C). Spices are arranged from highest to lowest percent of use, so their order varies. Histograms for hotter countries more closely approximate normal distributions than do those for cooler countries; the latter approximate negative exponential curves. (See pages 12–13)


Proportion of Recipes That Called For Each Spice
(a) Indonesia
Kurtosis = 1.3
Skew = 1.6
n = 120 recipes
garlic
onion
capsicums
coriander
pepper (b&w)
lemon/lime
galangal (laos)
ginger
tamarind
cumin
turmeric
lemon grass
bay leaf
dillweed
nutmeg
mace
cinnamon
cloves
cardamom
celery seed
paprika
basil
mint
parsley
mustard
allspice
anise
capers
caraway
fennel
fenugreek
green pepper
horseradish
juniper
marjoram
oregano
rosemary
saffron
sage
savory
sesame
tarragon
thyme
(c) Israel
Kurtosis = 7.8
Skew = 2.8
n = 145 recipes
pepper (b&w)
onion
garlic
lemon/lime
celery seed
parsley
capsicums
bay leaf
paprika
cinnamon
saffron
green pepper
nutmeg
mustard
ginger
cloves
mint
allspice
turmeric
cardamom
rosemary
cumin
coriander
caraway
thyme
horseradish
dillweed
tarragon
tamarind
sesame
savory
sage
oregano
marjoram
mace
lemon grass
juniper
galangal (laos)
fenugreek
fennel
capers
basil
anise
(e) Ireland
Kurtosis = 8.8
Skew = 3.0
n = 90 recipes
pepper (b&w)
onion
garlic
parsley
thyme
bay leaf
cloves
lemon/lime
paprika
sage
nutmeg
mustard
rosemary
mace
capsicums
ginger
allspice
cumin
cinnamon
celery seed
mint
caraway
fennel
oregano
coriander
galangal (laos)
tamarind
turmeric
lemon grass
dillweed
cardamom
basil
anise
capers
fenugreek
green pepper
horseradish
juniper
marjoram
saffron
savory
sesame
tarragon


(b) India
Kurtosis = 0.7
Skew = 1.0
n = 91 recipes
1.0
0.8
0.6
0.4
0.2
0.0
onion
ginger
capsicums
coriander
garlic
cloves
cinnamon
cumin
cardamom
pepper (b&w)
turmeric
bay leaf
mace
nutmeg
lemon/lime
mint
anise
mustard
saffron
tamarind
fenugreek
paprika
sesame
fennel
thyme
tarragon
savory
sage
rosemary
parsley
oregano
marjoram
lemon grass
juniper
horseradish
green pepper
galangal (laos)
dillweed
celery seed
caraway
capers
basil
allspice
(d) Hungary
Kurtosis = 7.2
Skew = 2.8
n = 80 recipes
1.0
0.8
0.6
0.4
0.2
0.0
onion
pepper (b&w)
paprika
parsley
green pepper
garlic
lemon/lime
bay leaf
caraway
marjoram
mustard
tarragon
ginger
cloves
horseradish
juniper
capsicums
dillweed
nutmeg
mace
capers
rosemary
coriander
galangal (laos)
tamarind
cumin
turmeric
lemon grass
cinnamon
cardamom
celery seed
basil
mint
allspice
anise
fennel
fenugreek
oregano
saffron
sage
savory
sesame
thyme
(f) Norway
Kurtosis = 19.2
Skew = 4.3
n = 77 recipes
1.0
0.8
0.6
0.4
0.2
0.0
pepper (b&w)
parsley
onion
lemon/lime
bay leaf
dillweed
nutmeg
capers
ginger
caraway
garlic
capsicums
coriander
galangal (laos)
tamarind
cumin
turmeric
lemon grass
mace
cinnamon
cloves
cardamom
celery seed
paprika
basil
mint
mustard
allspice
anise
fennel
fenugreek
green pepper
horseradish
juniper
marjoram
oregano
rosemary
saffron
sage
savory
sesame
tarragon
thyme

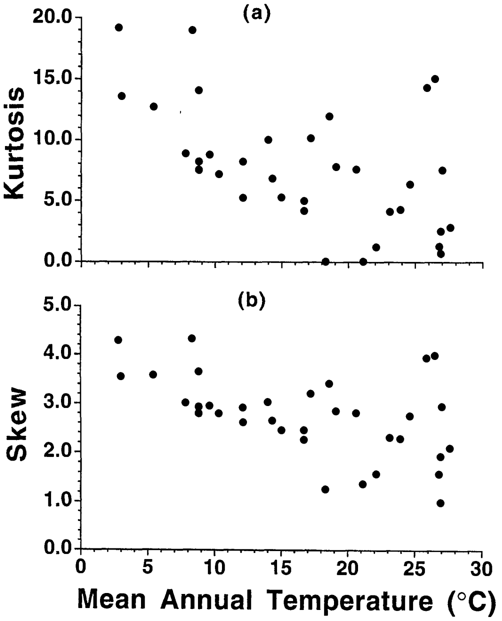


FIGURE 3. RELATIONSHIPS BETWEEN MEAN ANNUAL TEMPERATURE AND (a) KURTOSIS (PEAKEDNESS) AND (b) SKEW (ASYMMETRY) IN FREQUENCY-OF-USE HISTOGRAMS (AS IN FIGURE 2) FOR SPICES USED IN THE 34 NONREGIONAL COUNTRIES SAMPLED (EXCLUDING CHINA AND THE UNITED STATES; SEE TABLE 1).

By contrast, when precipitation is controlled statistically there are significant partial correlations (all $P<0.05$) between mean annual temperatures and numbers of different spices used in each country (partial $r=0.324$), proportions of recipes that call for at least one spice (partial $r=0.780$), mean numbers of spices per recipe (partial $r=0.612$), and proportions of spices used in each country that are called for in >40% of recipes (partial $r=0.485$); annual temperatures and proportions of spices called for in <5% of recipes are inversely correlated (partial $r=-0.466$). Use of capsicums, garlic, onion, anise, cinnamon, coriander, cumin, ginger, lemongrass and turmeric are positively correlated with mean temperatures (all significant, $P<0.05$) when precipitation is controlled statistically, whereas use of dill and parsley show a significant inverse correlation with temperatures.

ANTIBACTERIAL PROPERTIES OF SPICES

We obtained information on the antibacterial properties of 30 spices (Appendix A). All of them (100%) inhibit some species of bacteria, 24 (80%) inhibit ≥50%, 15 (50%) inhibit ≥75%, and 4 (13%) inhibit 100% (Figure 6). The average spice inhibits 67% (±23%) of bacteria. Garlic, onion, allspice and oregano inhibit every bacterium they have been tested on; at the other extreme, lemon and lime juice inhibit only 24% of bacteria.

There is a significant positive correlation ($r=0.668$, df=31, $P<0.001$) between mean annual temperatures and mean proportions of recipes that call for each highly inhibitory (≥75% bacterial inhibition) spice used in each country (Figure 7a). This means that more powerful spices are used more frequently in hotter climates. By contrast, there is no correlation between temperatures and mean proportions of recipes that call for each less inhibitory (<75% inhibition) spice used in each country ($r=0.248$, $P>0.10$; Figure 7b).

There is a positive but nonsignificant correlation between proportions of bacteria inhibited by each spice and proportions of countries that use each spice ($r=0.213$, df=28, $P=0.06$; Figure 8), suggesting that more powerful spices are used more widely. Even more interesting (Figure 9), proportions of 30 target bacterial species (Appendix B) inhibited by the spices called for in each country's recipes increase significantly with increasing annual temperatures ($r=0.516$, df=31, $P=0.001$). This implies that recipes from hotter countries have more antibacterial potential.

MACRONUTRITIONAL PROPERTIES OF SPICES

Considerable comparative information is available on the composition of foods and spices (e.g., Pruthi 1980; Tan 1985; Holland et al. 1991; Tainter and Grenis 1993). Virtually every spice in our analyses contains some protein (5–30 g/100 g), fat (0.5–35.0 g/100 g), and carbohydrates (5–50 g/100 g), and small quantities (0.1–15.0 mg/100 g) of four vitamins (carotene, thiamin, riboflavin and niacin) and ten inorganic elements. Among the latter, calcium, magnesium, phosphorus and potassium occur in 0.005–2.5 g/100 g concentrations, and chlorine, copper, iron, manganese, sodium and zinc occur in 0.001–1.0

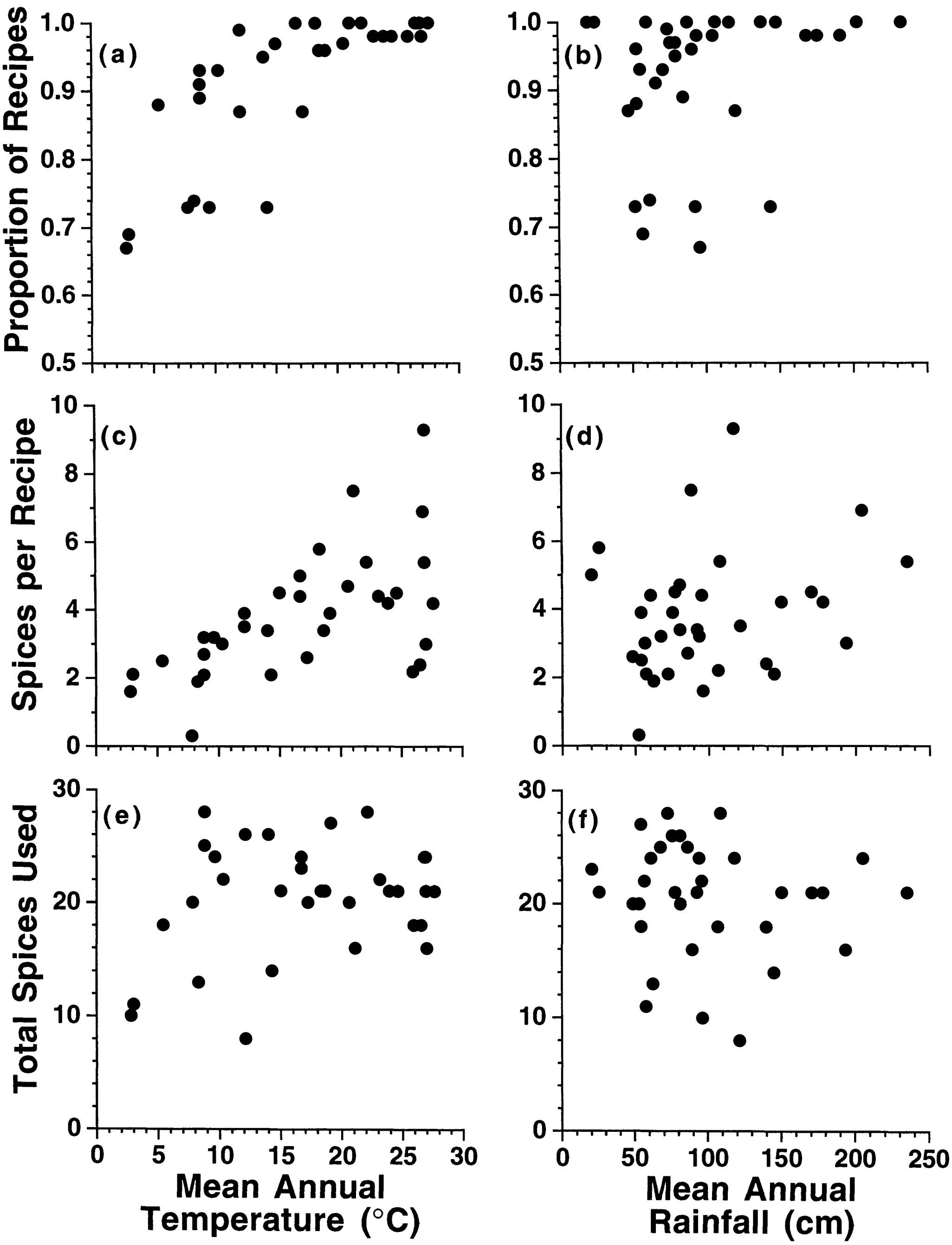


Figure 4. Relationships between mean annual temperature (left panels), mean annual precipitation (right panels), and (a,b) proportion of meat-based recipes that call for ≥1 spice; (c,d) mean number of spices per recipe; and (e,f) total number of spices used in the 34 nonregional countries.

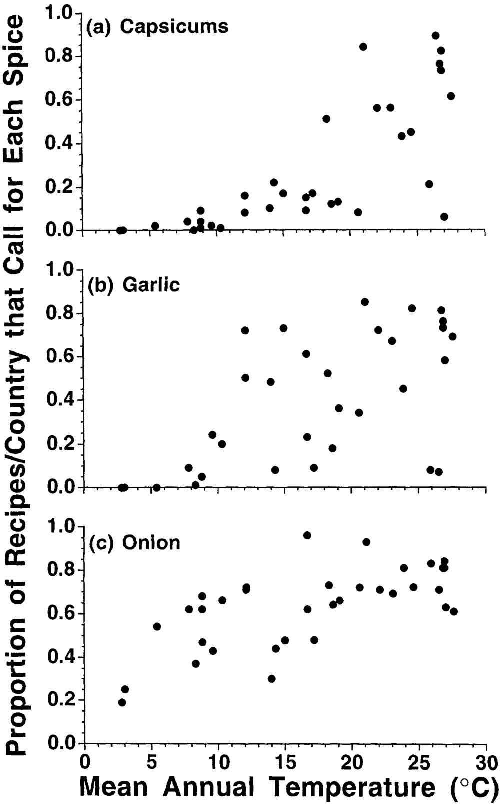


FIGURE 5. RELATIONSHIPS BETWEEN MEAN ANNUAL TEMPERATURE AND PROPORTION OF MEAT-BASED RECIPES THAT CALLED FOR CAPSICUMS (CHILIES), GARLIC, AND ONION IN THE 34 NONREGIONAL COUNTRIES (EXCLUDING CHINA AND THE UNITED STATES).

g/100 g concentrations. Few spices contain detectable amounts of fatty acids, cholesterol, starch, sugars or fiber.

All the macronutrients, vitamins and minerals contained in spices also are found in such common vegetables as carrots, beans, broccoli, rice, corn, lentils, potatoes and yams. Unlike spices, these vegetables also contain starch, sugars, fiber and fatty acids. In addition, the vegetables contain concentrations of carotene, thiamin, riboflavin and niacin equivalent to those found in most spices, a greater variety of vitamins (including B1, B2, C and folic acid), and higher concentrations of protein, carbohydrates, fat and inorganic elements than those found in most spices. In sum, compared to most vegetables, spices are poor sources of macronutrients, especially in the tiny quantities generally used in cooking.

SPICE USE AND AVAILABILITY

We determined the native and domesticated ranges of spice plants from data in Hornok (1992), Hylton (1974), Janick et al. (1981), Kowalchik and Hylton (1987), Schery (1972), and Morton (1976). We had assumed initially that most spice plants grow only in the tropics, but this turned out to be untrue (Table 2); we found no relationship between a country's mean annual temperature and the number of spice plant species that grow there ($r=0.081$, df=32, $P>0.10$; Figure 10). However, positive correlations do exist between the number of countries in which each spice plant grows and the number that use it ($r=0.352$, df=34, $P=0.035$; Figure 11), and between mean annual temperatures and proportions of spices used in the countries in which they grow ($r=0.444$, df=34, $P=0.010$). This means that although residents of hotter countries do not have more local spice plants to choose from than residents of cooler countries, people in hotter countries use a greater fraction of those spice plants that are available (especially the potent antimicrobials: Figure 7).

Spices are used both in countries where they grow and where they do not grow. No country's recipes include every spice that grows there. We quantified the variation by dividing the number of countries in which each spice grows by the number of countries that use each spice. In our sample, this index ranged from 1.0 to 0.1 (Figure 12) with a mean of 0.60 ± 0.25, indicating that most spices are used in more countries than they grow in. Five spices are used in the same number of countries as grow them. Among these, garlic and onions are grown in every country that uses them, whereas juniper, lemongrass and laos are used in some countries where they do not grow but are not used in the same number of countries where they do grow.

Proportions of recipes that call for each spice vary between countries where that spice grows versus where it does not grow. For 22 of the 30 spices (73%), proportional use is higher in countries where the plant grows; 14 of these

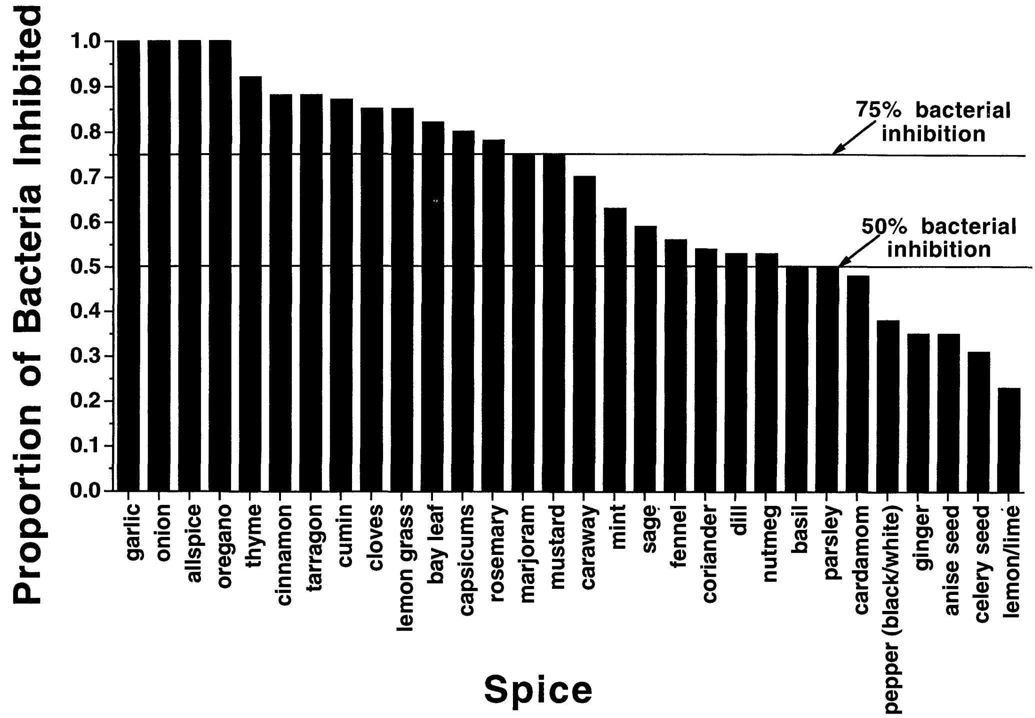


FIGURE 6. ANTIMICROBIAL PROPERTIES (INHIBITION OF GROWTH OR KILLING) OF 30 SPICES FOR WHICH APPROPRIATE DATA WERE AVAILABLE (SEE APPENDIX A), ARRAYED FROM GREATEST TO LEAST INHIBITION.

All spices inhibit some species of food-spoilage bacteria they have been tested on, and about half inhibit ≥75% of bacteria.

22 differences are significant (i.e., $P<0.05$, Mann-Whitney U tests). Among the eight spices used more frequently in countries where they do not grow, only one difference (allspice) is significant.

We investigated how proportions of recipes that call for each spice vary with mean annual temperatures among countries where the plant grows versus where it does not grow. Garlic and onions grow everywhere, and their frequencies of use are positively correlated with temperature (Figure 5). There also are significant positive correlations between temperature and frequency of use of capsicums (where chilies grow, $r=0.706$, $P<0.001$; where they do not grow, $r=0.852$, $P=0.001$), coriander (grows, $r=0.560$, $P=0.008$; does not grow, $r=0.648$, $P=0.017$), and cumin (grows, $r=0.719$, $P=0.008$; does not grow, $r=0.441$, $P=0.040$). For parsley, use is positively correlated with temperature only among countries where it grows ($r=0.539$, $P=0.031$), and for cinnamon ($r=0.632$, $P=0.001$), cardamom ($r=0.460$, $P=0.048$), and green peppers ($r=0.753$, $P=0.005$) significant positive correlations occur only where the plants do not grow. For the remaining spices, there are no correlations between frequencies of use and temperature when data are subdivided according to where each plant grows.

PEPPER AND LEMON AND LIME JUICE

Use patterns of lemon and lime juice and black and white pepper are unusual for several reasons. First, although they are among the five most frequently used spices (Figure 1) and appear in the meat-based cuisine of every country in our sample, they are among the least effective bacteriocides (Figures 6 and 8). Indeed, lemon and lime juice inhibit only

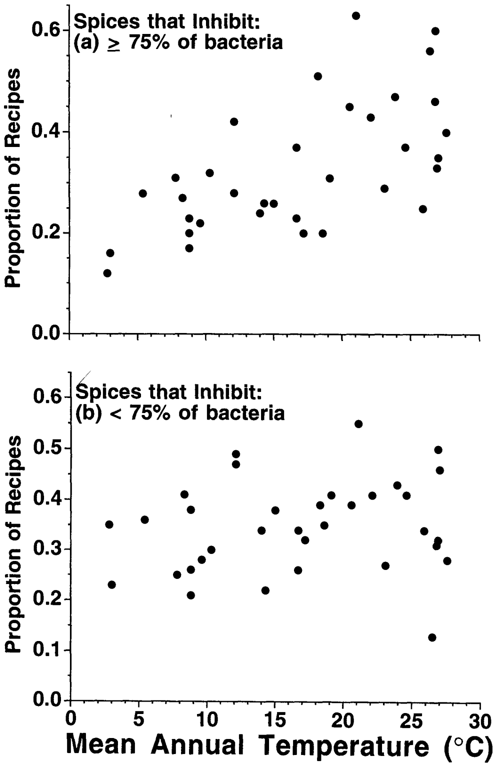


FIGURE 7. RELATIONSHIPS BETWEEN MEAN ANNUAL TEMPERATURE OF COUNTRIES AND MEAN PROPORTIONS OF MEAT-BASED RECIPES THAT CALL FOR EACH OF THE (a) HIGHLY INHIBITORY (≥75% BACTERIAL INHIBITION) SPICES USED IN THE COUNTRY, AND (b) LESS INHIBITORY (<75% INHIBITION) SPICES USED IN THE COUNTRY.

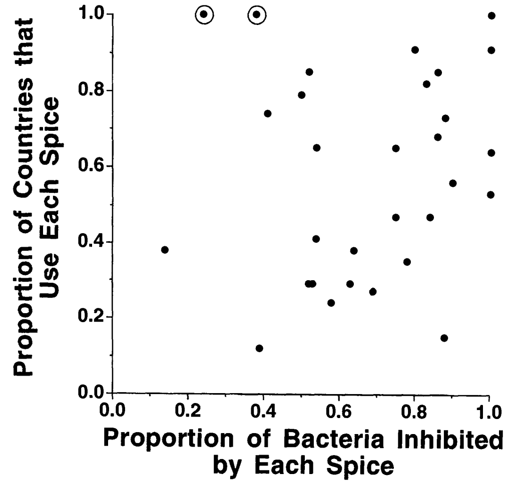


FIGURE 8. RELATIONSHIP BETWEEN PROPORTIONS OF BACTERIAL SPECIES INHIBITED BY EACH SPICE AND PROPORTIONS OF COUNTRIES WHOSE MEAT-BASED RECIPES CALL FOR THAT SPICE.

Circled data points are pepper and lemon/lime juice.

24% of bacteria studied, pepper only 38% (Appendix A); however, pepper does strongly inhibit some microorganisms, including the ubiquitous *Clostridium botulinum* (Nakatani 1994). Second, frequencies of use of pepper ($r=0.001$, df=32, $P=0.996$) and lemon and lime juice ($r=0.260$, $P=0.137$) are not correlated with a country's mean temperature (Figure 13), unlike the pattern for the other "top five" spices (onion, garlic and capsicums: Figure 5), as well as many others. Third, lemon and lime (*Citrus*) trees and pepper (*Piper*) plants grow naturally or are cultivated primarily in the tropics, so the majority of countries we sampled must import them (Table 2). This includes many countries with temperate and cold climates, where pepper is typically the most frequently used spice (e.g., Scandinavia; see Figure 2). The average frequency of use of pepper (mean proportion of recipes/country) is higher in countries where it does not grow ($\bar{X}=67.5 \pm 17.9\%$ of recipes) than where it does grow ($\bar{X}=57.0\% \pm 22.3\%$), but this difference is not significant.

REGIONAL DIFFERENCES WITHIN COUNTRIES

Although many countries include areas with different climates, we were able to locate regional cookbooks only for the United States and China (Table 1). In both countries, spice-use patterns differ between climatic regions (Figure 14). Frequency-of-use histograms for northeastern China, which has a temperate climate, are significantly ($P<0.05$) more kurtotic (12.81) and skewed (3.70) than those for southwestern China (kurtosis=6.42, skew=2.75), which has a subtropical climate. Likewise, histograms for the northern United States are significantly more kurtotic (8.07) and skewed (2.83) than those for the southern United States (kurtosis=3.61, skew=2.17).

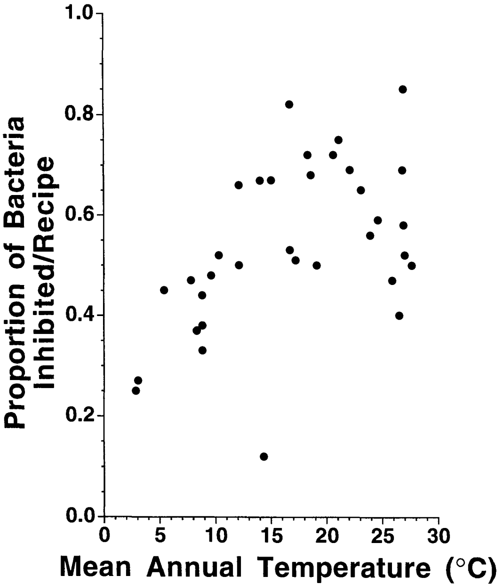


FIGURE 9. RELATIONSHIP BETWEEN MEAN ANNUAL TEMPERATURE AND (ESTIMATED) PROPORTIONS OF FOODBORNE BACTERIAL SPECIES INHIBITED PER RECIPE IN EACH COUNTRY (SEE TEXT AND APPENDIX B).
The "outlier" data point is Japan (see text).

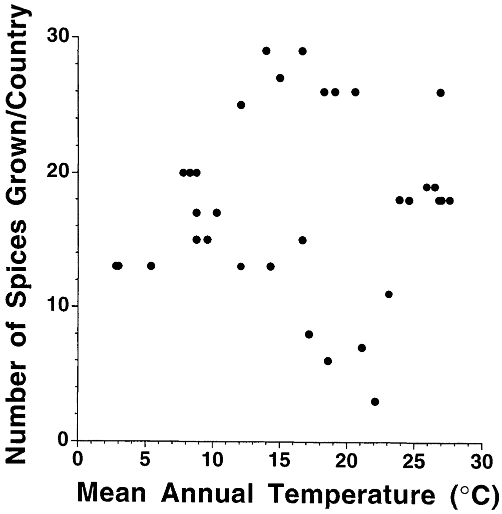


FIGURE 10. RELATIONSHIP BETWEEN MEAN ANNUAL TEMPERATURE OF COUNTRIES AND NUMBER OF SPICE PLANT SPECIES THAT ARE GROWN IN EACH COUNTRY.

These differences are mirrored in countries with different mean annual temperatures (see Figures 2 and 3).

Spice contents of meat-based recipes also vary between climatic regions within China and the United States. The pattern is similar to but less dramatic than that among different countries (e.g., Figure 4). In China the following are greater in the southwest than the northeast: (i) total number of spices used (15 vs. 14), (ii) proportion of recipes that call for at least one spice (93% vs. 90%), (iii) mean number of spices per recipe (3.2 vs. 2.3), and (iv) proportion of spices used in the region that are called for in >40% of recipes (21.3% vs. 13.8%); only the latter two differences are significant ($P<0.05$, χ^2 tests). The proportion of spices used that are rarely called for (in <5% of recipes) is higher in northeast than southwest China (50% vs. 42%), but not significantly so.

Within the United States the following are greater in the south than the north: (i) total number of spices used (35 vs. 33), (ii) proportion of recipes that call for at least one spice (99% vs. 90%), and (iii) proportion of spices used that are called for in >40% of recipes (11.3% vs. 6.0%); the latter two differences are significant ($P<0.05$). By contrast, the mean number of spices per recipe (5.4 vs. 5.0) and the proportion of spices used that are rarely called for (66% vs. 54%) is higher in the north than in the south; the latter difference is marginally significant ($P=0.05$).

Use of some individual spices also varies regionally. The ten most frequently called for spices are the same in the southern and northern United States, but their frequencies of use differ (Figure 14). Among these, pepper, garlic, capsicums and lemon and lime juice are used more frequently in southern than northern recipes (all significant, $P<0.01$, χ^2 tests), whereas the frequency of use of ginger, onion, green pepper, anise, allspice and celery seed does not differ significantly between regions. In China, the ten most frequently called for spices also are the same in the southwest and northeast. Pepper, garlic and capsicums are used more frequently in southwestern recipes (all significant, $P<0.01$), whereas the frequency of use of ginger, onion, anise, lemon and lime juice, green pepper, allspice and celery seed do not differ significantly between regions. No spice is used significantly more frequently in the northern than in the southern region of either the United States or China.

Recipes from cooler and warmer climatic regions of China and the United States call for spices with similar antibacterial properties. In the southern United States, 32% of the spices called for in >5% of recipes are highly inhibitory (inhibited ≥75% of bacteria) compared to 36% of spices used in the northern United States. In both southwest and northeast China 50% of the spices called for in >5% of recipes are highly inhibitory. Ginger and onion are the spices most frequently called for in both regions of both countries; as an antibacterial, onion is very potent, but ginger is relatively ineffective (Figure 6; Appendix A).

In general, frequency of use of the more potent spices in individual recipes differs between climatic regions. In the southern United States, 30% of recipes call for one or more of the nine highly inhibitory spices (>75% inhibition) used there, whereas in the north 22% of recipes call for at least one of these highly inhibitory spices ($P<0.05$, Mann-Whitney test). By contrast, in the southern United States only 25% of recipes call for at least one less inhibitory spice (<75% inhibition), versus 40% of northern recipes ($P<0.01$). In southwestern China, 40% of recipes call for at least one of the four highly inhibitory spices used there, versus 30% of recipes from northeastern China ($P<0.05$). In southwestern China, 39% of recipes call for at least one less inhibitory spice, versus 33% of northwestern recipes ($P>0.08$). As a result of these differences, the estimated proportion of bacterial species inhibited per recipe is 60% ± 25% in the southern United States versus 53% ± 32% in the north, and 33% ± 15% in southwestern China versus 30% ± 19% in the northeast; neither difference is significant.

DISCUSSION

The world over, spices have been used for centuries in preparation of meat for consumption or long-term storage (Parry 1953). Our analyses of traditional meat-based cuisines indicate, however, that spices are not used equally often in different countries and regions (Figures 1–3, 14). This variation enabled us to evaluate and compare predictions from alternative hypotheses that would explain these patterns of spice use. Although the data we compiled vary widely in quality, they are certainly unbiased with regard to any particular adaptive or nonadaptive hypothesis because they were all gathered for other purposes.

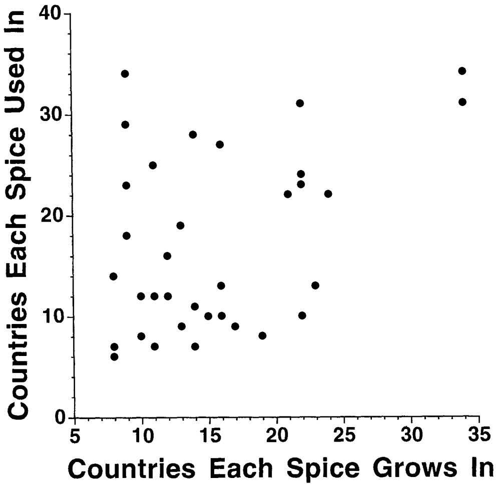


FIGURE 11. RELATIONSHIP BETWEEN THE NUMBER OF COUNTRIES IN WHICH EACH SPICE PLANT CAN BE GROWN (I.E., ITS NATIVE OR DOMESTICATED RANGE) AND THE NUMBER OF COUNTRIES WHOSE MEAT-BASED RECIPES CALL FOR THAT SPICE.

We hypothesized initially that the benefit of spices might lie in their antimicrobial properties. The secondary metabolites and essential oils that give spice plants their distinctive flavors probably evolved to counter biotic enemies such as herbivorous insects and vertebrates, fungi, pathogens, and parasites (e.g., Fraenkel 1959; Ehrlich and Raven 1964; Koul 1993; Walker 1994). This insight is potentially important because humans are afflicted by many of these same biotic enemies, in particular the bacteria and fungi that live on and in dead plant and animal matter (Johns 1990). If spices kill such microorganisms or inhibit their production of toxins, spice use might reduce chances of contracting foodborne illnesses or food poisoning.

Our results support several predictions of

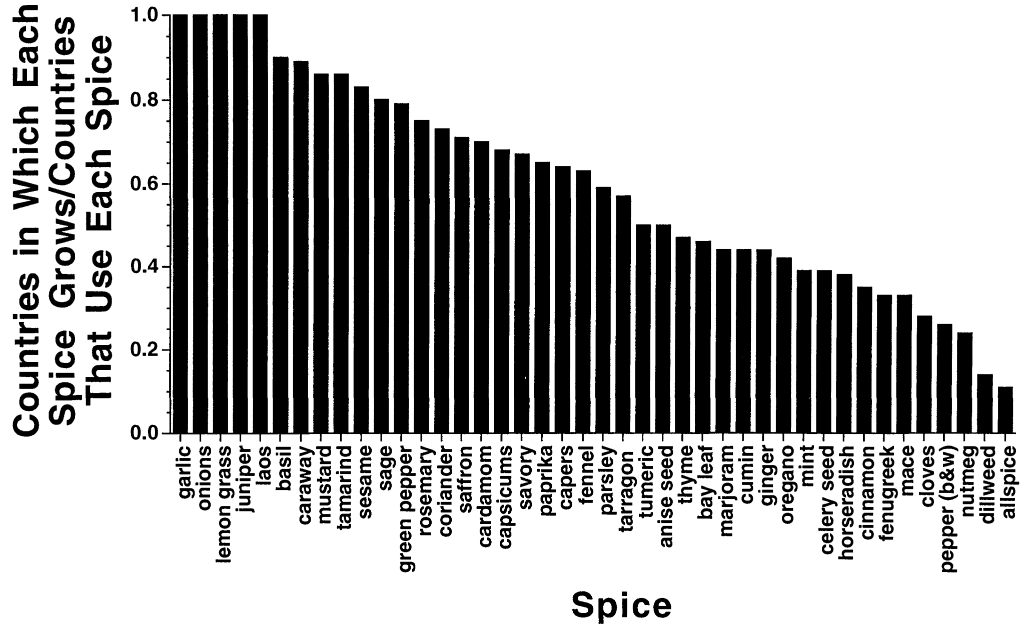


FIGURE 12. SPICES ARE USED BOTH WHERE THEY GROW AND WHERE THEY DO NOT GROW.
Each bar represents the number of countries in which each spice grows naturally or is cultivated, divided by the number of countries that use each spice. For most spices the index is <1.0, indicating that they are used in more countries than they grow in.

this hypothesis. In agreement with previous reports (e.g., Shelef 1984; Deans and Ritchie 1987; Zaika 1988; Beuchat 1994; Nakatani 1994), all spices for which we could locate appropriate information have some antibacterial effects (Figure 6; Appendix A): half inhibit ⩾75% of bacteria, and four (garlic, onion, allspice and oregano) inhibit 100% of those bacteria tested. In addition, many spices are powerful fungicides (e.g., Thompson and Cannon 1986; Thompson 1989; Ahmed et al. 1994; Beuchat 1994), and can thus prevent production of deadly fungal metabolites (e.g., mycotoxin: Beuchat 1994).

Many spices are also synergists. When combined, those spices exhibit greater antibacterial effects than when each is used alone (Shelef 1984; Johns 1990; Beckstrom-Sternberg and Duke 1994). This is interesting because recipes in our sample call for an average of four different spices. Some spices are so frequently combined that the blends have acquired special names (see Tainter and Grenis 1993:147–154), such as "chili powder" (typically a mixture of red pepper, onion, paprika, garlic, cumin and oregano) and "oriental five spice" (pepper, cinnamon, anise, fennel and cloves). A particularly intriguing example is the French "quatre epices" (pepper, cloves, ginger and nutmeg), which often is used in making sausages. Sausages (*botulus* in Latin) are a rich medium for bacterial growth, and frequently have been implicated as the source of death from botulism toxin; the value of antibacterial compounds in spices for sausage preservation and prevention of toxin production is obvious. Use of multiple spices, especially when combined with citric or acetic acid and salt, and then heated, produces the most powerful antimicrobial effects (Kurita and Koike 1982; Gould 1992; Liu and Nakano 1996; Ziauddin et al. 1996).

The antimicrobial hypothesis assumes that concentrations of spice chemicals in meat-based recipes are sufficient to produce the desirable effects, and that these effects are not destroyed by cooking. Analyses of spice concentrations in prepared dishes, along with their combined antimicrobial potency, which are required to evaluate this assumption, are just beginning (see Board and Gould 1991; Rusul et al. 1997). Concentrations of spice extracts used to flavor and preserve commercial meat products, pickles and breads generally range from 0.5 to 1.0 g/kg (1:2000–1:1000 or 500–1000 ppm; Salzer 1982), although higher concentrations (>2000 ppm) of some spices are required to preserve certain foods (Galli et al. 1985). Many of the studies of spices as antibacterials (Appendix A) tested concentrations <1000 ppm (e.g., Huhtanen 1980; Kivanc and Akgul 1986; Zaika 1988; Ismaiel and Pierson 1990a; Kivanc et al. 1991). We calculated that the recipes in our sample call for roughly 0.25–3.0 g/kg of spices (1:4000–1:3000 or 250–3000 ppm). This implies that concentrations of spices used in cooking are sufficient to yield useful antibacterial effects, in agreement with Shelef (1984), Giese (1994), and Liu and Nakano (1996). This may not always be true, however. Farbrood et al. (1976) reported that rosemary inhibited the growth of *Staphylococcus aureus* in media at concentrations of 0.1%, but was effective in meat only at concentrations over an order of magnitude higher.

Effects of cooking on the antimicrobial potency of spices are essentially unknown. On the one hand, commercial extraction of spice oleoresins and essential oils often involve steam distillation at high temperatures. Gas chromatograms that compare steam-distilled spice chemicals against CO_2-extracted products (at low temperatures) typically show similar patterns (Moyler 1994), indicating that spices are thermostable. Furthermore, Diebel and Banwart (1984) found that oregano, sage and ground cloves still inhibited *Campylobacter jejuni* (a major cause of gastroenteritis) after 16 hours of simmering at 25° C and 42° C. On the other hand, Chen et al. (1985) reported that higher cooking temperatures destroyed the antimicrobial effects of a few other spices.

Different spices are often added to recipes at different points in preparation. For example, onion, garlic, pepper and rosemary typically are added at the beginning, whereas parsley and cilantro (coriander leaf) generally are added near the end. According to cookbook authors, the "delicate" flavors of the latter would be destroyed by cooking. If the most thermostable spices are usually added early in preparation and the most thermolabile spices are added near the end of cooking (or are used primarily as condiments), these differences in timing of use may relate to maintaining beneficial (antimicrobial) properties until food is served. Loss of flavor would be a useful proximate indicator of loss of antimicrobial potency.

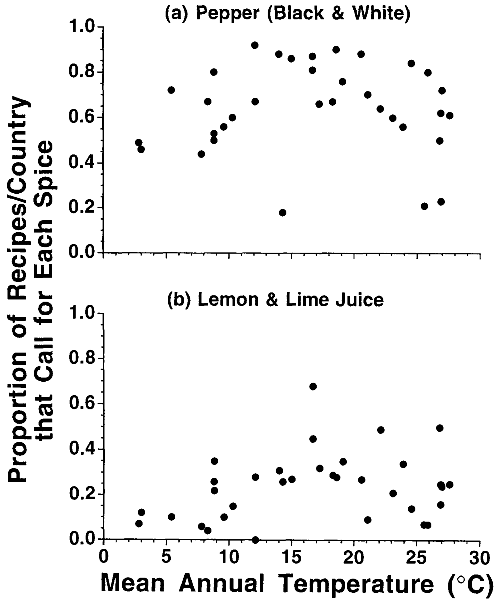


FIGURE 13. RELATIONSHIPS BETWEEN MEAN ANNUAL TEMPERATURE OF COUNTRIES AND PROPORTION OF MEAT-BASED RECIPES THAT CALL FOR (a) BLACK OR WHITE PEPPER, AND (b) LEMON OR LIME JUICE.

A second prediction of the antimicrobial hypothesis is that spice use should be heaviest in areas where foods spoil most quickly. Hazard analyses and epidemiological studies indicate that rates of bacterial growth increase dramatically with air temperature (Genigeorgis 1981; Brown 1982; Bryan 1988). Meat dishes that are prepared in advance and stored at room temperatures for more than a few hours, especially in tropical climates, typically show massive increases in bacterial counts (Bryan et al. 1979; Michanie et al. 1988; Hobbs and Roberts 1993). Moreover, bacteria are confined to the surface of meat during the logarithmic phase of growth (Gill and Penny

1977), and that is where spices would be effective against them. Therefore it is relevant to ask how spice use changes as temperature varies.

We found that countries with hotter climates used spices more frequently than countries with cooler climates (Figures 2–5). Indeed, in hot countries nearly every meat-based recipe calls for at least one spice and most include many spices, whereas in cooler countries substantial fractions of dishes are prepared without spices, or with just a few. The result is a significant positive correlation between mean temperatures and estimated proportions of foodborne bacteria inhibited per recipe (Figure 9). Of course, temperatures within dwellings, particularly in food preparation and storage areas, may differ from those of the outside air, but usually it is even hotter in the "kitchen" (e.g., Michanie et al. 1988).

In climates with distinctive seasons, annual mean temperatures do not accurately reflect temperatures characteristic of each season. A more detailed analysis would consider spice-use patterns relative to seasonal differences in foodborne diseases. For example, in the north temperate zone, outbreaks of bacterial food poisoning peak during the hottest months (e.g., in summer: *Salmonella*: Doyle and Cliver 1990; *E. coli*: Griffin and Tauxe 1991). The antimicrobial hypothesis predicts that more potent spices and a greater variety of spices should characterize dishes typically prepared in "summer" than in "winter." Unfortunately, we were unable to locate enough seasonal recipes for any country to evaluate this corollary.

Differences in spice use between northern and southern regions of the United States and China (Figure 14) mirror differences among countries (Figures 2–4), but these differences are relatively smaller. This is unsurprising since regional differences in the United States have had only about 200 years to develop, and temperature differentials are not great (Table 1). Differences between northeastern and southwestern Chinese cuisine have had considerably longer to develop. However, effects of altitude may obfuscate regional differences in China. We expect the cuisine of people living at higher elevations (cooler climates) to contain fewer spices and less potent spices than the cuisine of people living at lower elevations, where unrefrigerated foods spoil faster. Elevations in southern and western China vary widely. Unfortunately, we do not know if recipes from these regions originated in the lowlands or highlands. If the latter, they should resemble recipes from northern and eastern China in spice-use patterns. A high frequency of recipes from high-altitude areas would blur differences between the southwest and northeast.

Proportions of recipes that call for many individual spices vary systematically with climate, both within and among countries. Use of ten spices increases with temperature, including some of the most potent antimicrobials, such as capsicums, garlic, onions, cinnamon, cumin and lemongrass (Figures 5 and 6; Appendix A). Garlic and capsicums also are used more frequently in the southern than the northern United States, and garlic and capsicums are used more frequently in southwest than northeast China. Frequency of use is inversely related to temperature only for parsley and dill, and these are among the least potent antibacterials (Figure 6).

Of course, our various tests of the antimicrobial hypothesis assume that "traditional" meat-based recipes existed prior to the widespread availability of refrigeration, so that a country's meat spoilage rate roughly correlates with its annual temperature. We cannot directly evaluate this assumption, because authors of cookbooks rarely knew the history of their recipes. However, any recipe in existence for more than five generations (80–100 years) predates the widespread availability of electricity and refrigeration. We tried to bias our sample in favor of these older recipes through judicious selection of cookbooks (i.e., we avoided experimental and modern cookbooks and ignored recipes that were said to have been recently developed). Although no one knows precisely how long spice plants have been grown in any particular region or country, spices have been cultivated for thousands of years in the Old World (Zohary and Hopf 1994) and hundreds of years in the New World (Coe 1994).

Spice use does not vary systematically among countries in relation to average annual precipitation. Partial correlation analyses confirm the significant effects of temperature when precipitation is controlled for statistically, and the insignificant effects of precipitation on

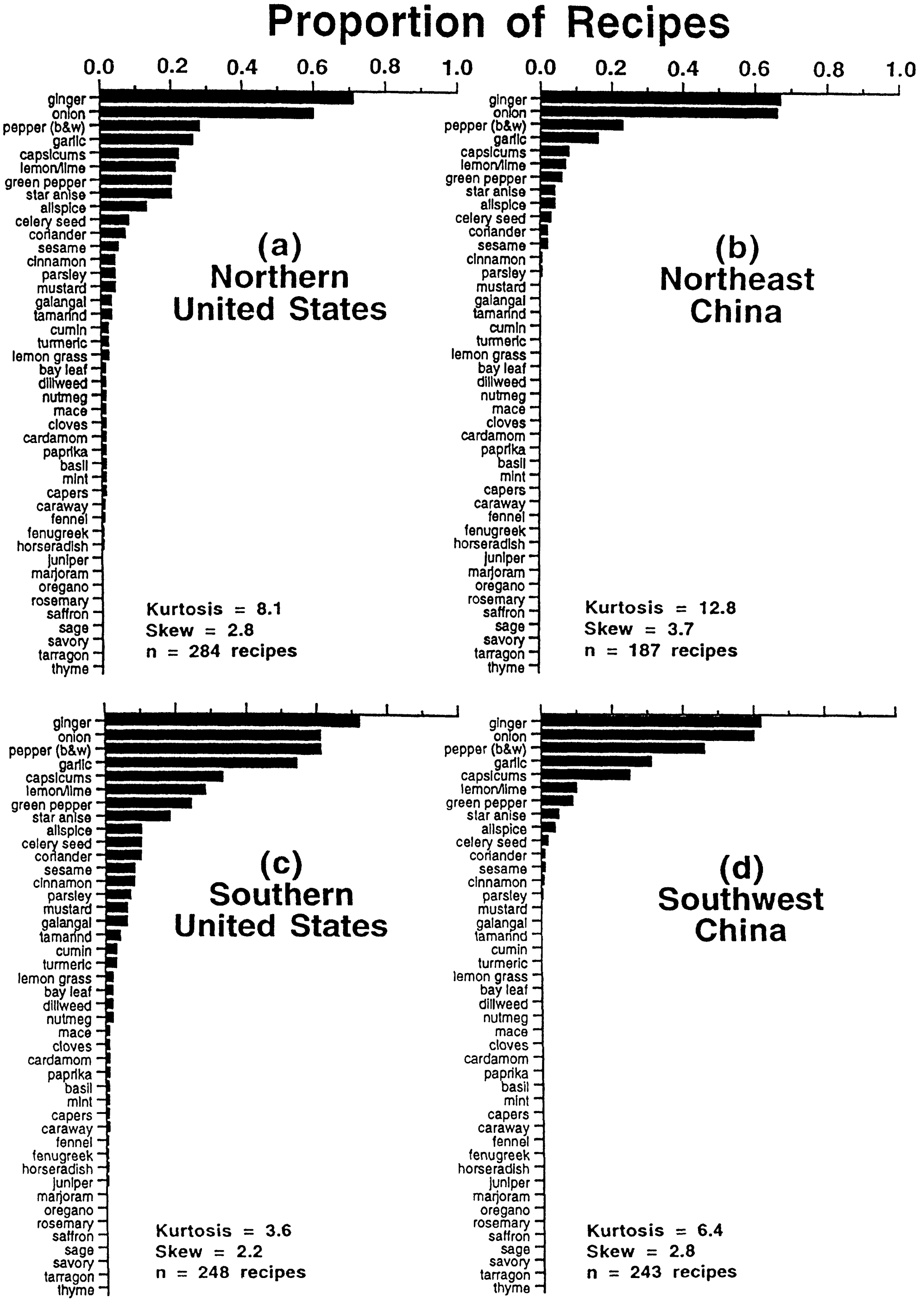


FIGURE 14. FREQUENCY-OF-USE HISTOGRAMS SHOWING PROPORTION OF MEAT-BASED RECIPES THAT CALL FOR EACH SPICE IN WARMER (SOUTHERN) AND COOLER (NORTHERN) CLIMATIC REGIONS OF CHINA AND THE UNITED STATES.

spice use when temperature is statistically controlled. Although these results offer no definite support for the antimicrobial hypothesis, they also do not militate against it. First, temperature typically is more important for bacterial growth than humidity (Bryan et al. 1979; Gilbert 1979; Hobbs and Roberts 1993); moreover, concentrations of airborne bacteria can actually be reduced by high relative humidity or rain, whereas concentrations can be increased by high temperatures or wind velocities (e.g., Bovallius et al. 1978). Second, mean annual precipitation may not reflect the humidity that is typical of a country or region if precipitation is seasonal, the soil porous, or surface evaporation rapid. Third, in many countries open fires are closely associated with food preparation and storage areas (e.g., Michanie et al. 1988), so humidities in "kitchens" may be lower (and temperatures higher) than in the outside air.

A third prediction of the antimicrobial hypothesis is that the most potent spices should be favored where foods spoil fastest. It is conventional wisdom that food from hot climates tends to be spicy ("hot"). Indeed, we found that meat-based recipes from hot countries and hot regions of China and the United States generally contain more spices and spices with more potent antibacterial effects than cuisines from cooler countries or cooler regions of countries. There are significant positive correlations between annual temperatures and use of cinnamon, cumin, onion, garlic and capsicums (Figure 5), all of which are powerful antibacterials (Figure 6). There also is a strong correlation between temperatures and proportions of recipes that call for the highly inhibitory ($\geq 75\%$ inhibition) spices used in each country (Figure 7a), and a positive but nonsignificant relationship between proportions of countries that use each spice and proportions of bacterial species each spice inhibits (Figure 8). By contrast, there is no correlation between temperatures and proportions of recipes that call for each less inhibitory spice ($<75\%$ inhibition; Figure 7b). Although a similar fraction of the spices used in cooler and hotter regions of the United States and China are highly inhibitory, proportions of recipes calling for at least one highly inhibitory spice are significantly greater in hotter (southern) regions of both countries.

The final prediction of the antimicrobial hypothesis is that the spices used most frequently in a region should be particularly effective against local food-spoilage microorganisms. Evaluating this requires comprehensive knowledge of indigenous bacteria. Unfortunately, this information does not exist for any country. We attempted to generate lists of bacteria involved in foodborne disease outbreaks from data supplied by the World Health Organization and the U.S. Centers for Disease Control. Such information was available only for nine countries, however, most of them European, and among these traditional cookbooks were available for only five. More importantly, only selected bacteria from certain recent outbreaks were identified to species, selected bacteria differed among countries, and causes of many outbreaks remain unidentified. Thus, the data were inadequate for generating comprehensive lists of indigenous bacteria.

Although we were unable to test this fourth prediction directly, we note that there is a strong positive correlation between mean temperatures and estimated proportions of foodborne bacteria inhibited by the spices in an average recipe (Figure 9). The 30 target bacteria for this analysis (Appendix B) were chosen because they have been experimentally challenged with the greatest number of spices. Most of these microorganisms are widely distributed geographically (e.g., *Aeromonas hydrophila, Bacillus cereus, B. subtilus, Clostridium botulinum, Listeria monocytogenes, Escherichia coli, Salmonella pullorum, Staphylococcus aureus*), so they are likely contaminants in the foods of most countries. Moreover, actual proportions of indigenous foodborne bacteria inhibited per recipe probably are higher than indicated in Figure 9 for countries with mean temperatures >21° C because the spices used most frequently in hot climates (e.g., capsicums, garlic, onion, cinnamon and cumin) are such powerful antibacterials (Figure 6). Use of these broad-spectrum antimicrobial chemicals should raise the fraction of indigenous bacteria inhibited in hotter climates, making the actual relationship between temperature and inhibition per recipe even stronger.

There is an intriguing, order-of-magnitude difference in the frequency of foodborne illnesses between modern Japan and Korea. From 1971 to 1990 food poisoning, primarily of bacterial origin, affected 29.2/100,000 Japanese but only 3.0/100,000 Koreans (Lee et al. 1996). This difference seems surprising, especially since these nearby countries have similar, temperate climates. Lee et al. (1996) suggested that this difference is owing to cultural differences in food handling and preparation procedures, and this may well be so. But, in addition, Korean recipes are spicier. Compared to Japanese recipes, Korean recipes (i) more frequently call for at least one spice (88% vs. 74%), (ii) contain more spices per recipe on average (3.6 vs. 2.2), and (iii) more frequently call for ≥1 highly inhibitory spice (75% vs. 54%). As a result, the estimated proportion of foodborne bacteria inhibited by an average recipe is significantly ($P<0.01$) higher in Korean (51%) than Japanese cuisine (12%; see Figure 9). Why traditional Japanese recipes do not call for more potent spices is unknown. One possibility is that the spices used in traditional Japanese cuisine were adequate protection against bacteria when fresh seafood was available from local waters. Today, since more food is imported and comes from farther away, it may contain more species of foodborne bacteria and fungi. Traditional Japanese recipes may not include enough spices (antimicrobials) to cope with these new infestations.

Use patterns of pepper and lemon and lime juice at first appear to contradict the antimicrobial hypothesis. Although they are among the five most frequently used spices (Figure 1), they are among the five least effective against bacteria (Figure 6), and their frequency of use is not positively correlated with temperature (Figure 13). Moreover, most countries in our sample import these spices; *Citrus* trees and *Piper* plants are available locally in only 9–11 countries with warm climates (Table 2).

Interestingly, however, lemon and lime juice (citric acid) act synergistically to enhance the antibacterial effects of other spices (Bachmann 1916; Booth and Kroll 1989; Giese 1994; Ziauddin et al. 1996), probably because low pH disrupts bacterial cell membrane function. As a result, foods to which an acid is added require relatively mild heating to cause the same levels of bacterial mortality that takes place in foods that are cooked longer and at higher temperatures in the absence of the acid (Gould et al. 1983; Gould 1992). Pepper also has synergistic effects; it functions as a bioavailability enhancer, increasing the rate at which the active ingredients in other spice chemicals become physiologically available to or are absorbed by epithelial cells (Johri and Zutshi 1992), and also presumably by microorganisms. In addition, pepper is a powerful antioxidant, which by itself often is sufficient to prevent oxidative food deterioration (Lin 1994). Perhaps the widespread use of pepper and citrus juices relates to their properties as antimicrobial synergists (and antioxidants).

Under the antimicrobial hypothesis, correlations between frequencies of spice use and temperature occur because food-spoilage microorganisms multiply faster in hotter climates, making antimicrobial substances more valuable there. But why don't traditional recipes from countries with cool climates call for (potent) spices more often? Certainly some tropical spices (e.g., allspice, cinnamon, laos and cloves) may not have been readily available in certain countries when traditional recipes were being developed. Nevertheless, most spices have rather broad distributions (Table 2). Moreover, lemon and lime trees and pepper only grow in a fraction of the countries we sampled (all tropical), and yet these spices are used far and wide, including in Scandinavia.

Part of the answer may be that using spices involves certain costs: (1) financial costs associated with procuring dried plants that do not grow locally; (2) illnesses caused by ingesting spices that are themselves contaminated with bacteria or fungi (e.g., due to lengthy or improper storage: Pruthi 1980; Pafumi 1986); and (3) short-term and long-term physiological costs associated with ingesting plant secondary compounds and essential oils (Saxe 1987; Johns 1990). Regarding the latter, Beier and Nigg (1994) comprehensively reviewed the mutagenic, teratogenic, carcinogenic and allergenic effects of plant secondary compounds, including many spices. In hot climates, the benefits of avoiding food poisoning and foodborne illnesses apparently outweigh dangers associated with ingesting these chemicals. In cool climates, however, there probably are fewer indigenous pathogens, and foods may decay slowly enough that further retardation of spoilage may not be worth the associated health risks of ingesting spices, or the expense of obtaining them.

Strong-tasting and spicy foods often are unacceptable to pregnant women (Profet 1992, 1996), especially during the first trimester. Profet suggested that morning sickness imposes adaptive dietary restrictions on the mother. Women who experience morning sickness have lower miscarriage rates than women who do not (Weigel and Weigel 1989), perhaps because the former minimize fetal exposure to dangerous substances in food, such as plant secondary compounds. Likewise, young children, who are undergoing rapid growth and are more susceptible than adults to developmental abnormalities, find spicy foods unacceptable (Rozin 1980; Rozin and Schiller 1980). Perhaps both children and pregnant women avoid strong (spicy) tastes, even though this potentially exposes them to greater dangers of food poisoning and foodborne illnesses, because of the even greater risks associated with ingesting potentially mutagenic chemicals. Context-dependent shifts in spice use between childhood and adulthood, and between pregnancy and nonpregnancy, may thus have a common, adaptive basis.

Janzen (1978) suggested that animals (including humans) consume plants containing unusual-tasting or foul-tasting and potentially poisonous compounds as a means of "self-medication" (reviewed by Clayton and Wolfe 1993). An often cited example is the ingestion of the leaves of putatively medicinal plants by chimpanzees afflicted by gastrointestinal parasites and other maladies (Huffman and Wrangham 1994). Virtually every spice in our sample has an ethnopharmacological use among traditional societies, often as a topical or an ingested antimicrobial (e.g., Martinez 1944; Perry 1980; Koo 1984; Etkin 1986; Chevallier 1996). A few spices, particularly garlic, ginger, cinnamon and capsicums, have for centuries been taken to counteract a broad spectrum of ailments, including pneumonia, dysentery, kidney stones, high blood pressure, worms and nausea (Beuchat and Golden 1989; Duke 1994; Cichewicz and Thorpe 1996).

Use of spices in food preparation generally differs in two ways from their use in traditional medicine, however. In cooking, spices are added routinely (regardless of health status of consumers) and in relatively tiny quantities, whereas medicinal uses of spices are occasional (in response to specific maladies) and usually in much larger quantities. These differences imply that spices are used primarily to remedy chronic problems rather than acute illnesses. Among chronic problems, spices might (i) supply necessary micronutrients (Johns and Chapman 1995; Milner 1996), (ii) combat persistent enteric infections, or (iii) kill microorganisms that usually colonize food. Unfortunately, the micronutritional values of most spices are unknown. However, positive correlations between annual temperatures and use of spices (Figures 2, 4, 5 and 7) and regional differences within countries are not predicted by (i), unless for some reason people in warmer climates require more micronutrients. Regarding (ii), the rapidity with which ingested spice chemicals are catabolized and their effects on enteric infections are unknown. However, most spices are not ingested solely in response to feeling ill, and spices are routinely used in food preparation but not routinely ingested alone (garlic is a notable exception). Thus, presently available data are most consistent with the hypothesis (iii) that parasites and pathogens on and in foods are the primary targets of spice chemicals.

Although humans are the only creatures that elaborately prepare their foods, it is an interesting question whether other species regularly "spice" their diets with small quantities of plant secondary compounds. Extensive information is available on the food habits of wild mammals, based mainly on analyses of feces and stomach contents. Deer (Klimstra and Dooley 1990; Johnson et al. 1995) and elk (Sherlock and Fairley 1993) consistently ingest trace amounts of aromatic plants that are foul-tasting or bitter-tasting to humans. "Vegetation" also forms a small but significant fraction (5–35%) of the diet of most wild carnivores, such as red foxes (Cavallini and Volpi 1995; Ferrari and Weber 1995), coyotes (Berg and Chesness 1978; Parker 1995), bobcats (Maehr and Brady 1986), and cougars (Robinette et al. 1959; Ackerman et al. 1984). Undoubtedly some of this vegetation is ingested for its macronutrients, as when meat is scarce.

Nonetheless, frequent ingestion of vegetation is interesting because mammalian carnivores, particularly those that eat carrion, are so frequently exposed to food-spoilage bacteria and fungi. It would interesting to know if a coyote benefits in the context of inhibiting such microorganisms by nipping a few sage leaves or juniper berries.

Our data are relevant to several alternatives to the antimicrobial hypothesis. First is the possibility that spices provide macronutrients, vitamins or minerals. However, compared to spices, most common vegetables contain more protein, carbohydrates, fat, starch, fiber, minerals and a greater variety of vitamins than do spices (Tan 1985; Holland et al. 1991). No "nutritional facts" panel even appears on the labels of most commercial spices in the United States (exceptions are paprika and chili powder, which contain vitamin A). For these reasons several authorities (e.g., Ensminger et al.1983; Farrell 1990; Kirschmann and Dunne 1984) have stated that spices are of little or no nutritive value, especially in the tiny quantities in which they are generally consumed.

Spices may supply rare micronutrients, however. Plant secondary compounds, including those found in some spices (particularly garlic and onions), can have beneficial effects such as aiding digestion, modulating energy metabolism, and acting as antioxidants (Johns 1990; Johns and Chapman 1995). Some phytochemicals also may help postpone degenerative diseases such as diabetes, coronary heart disease and cancer (Milner 1996). Whether the majority of spices in our sample could provide these benefits, and whether the quantities recipes call for supply sufficient micronutrients to do so, are just beginning to be investigated (Aruoma et al. 1997). Regardless, the micronutrition hypothesis does not predict or explain the multiple positive correlations we found between mean temperatures and spice use (Figures 2, 4 and 7), particularly for capsaicins and other spices with powerful antibacterial properties (Figure 5). Thus, dietary supplementation does not appear to be the sole, or even the primary, reason for the popularity of spices, especially in hot climates.

A second hypothesis is that spices are used because they disguise the smell or taste of spoiled foods (Barker 1982; Govindarajan 1985). Our finding that traditional recipes from hotter countries call for more spices (Figure 4), especially pungent spices, is consistent with this hypothesis because there would more often be foul smells or bad tastes to "cover up" owing to rapid spoilage.

The "cover-up" hypothesis ignores the potentially serious negative consequences of ingesting bacteria-laced foods, however. Across the world, foodborne bacteria (especially species of *Clostridium, Escherichia, Listeria, Salmonella, Staphylococcus, Streptococcus*; see Evans and Brachman 1991; Jay 1994; Todd 1994, 1996) or their toxins debilitate millions of people annually and kill thousands. In the United States alone, foodborne illnesses afflict an estimated 80 million people per year (World Health Report 1996), and one in ten Americans experiences bacteria-related food poisoning annually (Hui et al. 1994). Moreover, new foodborne pathogens are continually evolving (e.g., Notermans and Hoogenboom-Verdegaad 1992; Butler 1996). Disguising tastes associated with spoilage or contamination potentially increases exposure to foodborne diseases. Even poorly nourished individuals might be better off recognizing and passing up tainted foods, especially meat products (Roberts 1990; Sockett 1995), when there is a chance of ingesting potentially deadly quantities of microorganisms or their toxins. It may even be that the advantages of recognizing and avoiding spoiled or contaminated foods explain the sensitivity of our olfactory and gustatory systems to smells and tastes of decay. Thus, from an evolutionary perspective, the "cover-up" hypothesis is seriously flawed.

A third alternative hypothesis is that spicy foods are preferred in hot climates because they help cool the body evaporatively by increasing perspiration (see Rozin and Schiller 1980; Bosland 1994). Capsicums can produce hypothermia, either through a gustofacial sweating reflex or direct action on the hypothalamus (Rozin and Schiller 1980). However, most spices whose use increases with mean temperatures (e.g., garlic, onion, anise, cinnamon, coriander, ginger, lemongrass) do not produce hypothermia, and even chilies do not increase perspiration in many people (Rozin and Schiller 1980). Moreover, sweating is a metabolically expensive way to cool off, and it requires abundant water to sustain it. In the context of the spice-use patterns we have identified, the evaporative cooling hypothesis cannot be a general explanation.

A final possibility is that spices confer no benefits, and that people simply use whichever aromatic plants are at hand to improve the taste of food. Harris (1985:15), Nesse and Williams (1994:147–151), and Letarte et al. (1997) discussed how human taste receptors and gustatory preferences have been shaped by nutritional benefits normally associated with favored flavors. Potentially edible items are expected to be tasty if their chemical constituents match closely enough those normally found in nutritious foods. This "null" hypothesis predicts that spice chemicals should be highly palatable, and that spice-use patterns should correspond closely to natural ranges of spice plants.

Neither prediction is supported. First, flavors of many widely used spices are not immediately appealing. Indeed, pungent spices like garlic, ginger, onion, anise, turmeric and black pepper initially are unappealing to most people, especially to children (Rozin 1980), and the capsaicin in hot chili peppers causes painful sensations (Caterina et al. 1997). For most disagreeable substances, an initial negative response is sufficient to maintain avoidance throughout an individual's life. However, preferences for spices develop with age, usually under familial guidance (Rozin and Schiller 1980). The fact that parents encourage their children to eat (displeasing) spices, and that children come to prefer them by adolescence, strongly suggests that using spices is somehow beneficial.

Second, people do not use every spice that grows in their country (Figure 11), but they do use many spices that must be imported (Figure 12), and for centuries have gone to great lengths to obtain them (e.g., Govindarajan 1985). An extreme example is pepper, which is one of the most frequently used spices in all 36 countries we sampled (Figure 1), but which grows in only nine of them (Table 2). Pepper is the most frequently imported spice into the United States today (about 87 million pounds in 1991: Tainter and Grenis 1993).

Although local availability is not a sufficient explanation, it certainly affects spice-use patterns because proportions of recipes that call for most spices are higher in countries where those spices grow. Moreover, recipes of hotter countries call for greater fractions of locally available spice plants, as indicated by the positive correlation between temperatures and proportions of spices used in the countries in which they grow. However, since there is no relationship between mean annual temperatures and numbers of spices that grow in each country (Figure 10), the multiple positive correlations between temperatures and frequencies of spice use (Figures 2, 4, 5 and 7) are not simply owing to greater spice plant availability in hotter countries. In sum, local availability of a spice plant does not necessarily mean that residents will use it, and lack of local availability does not mean that residents will not use it.

Rozin (1982) hypothesized that humans seek variety in foods to ensure that they obtain a nutritionally balanced diet. It is well established that the perceived diversity of foods consumed positively influences the amount consumed (Rozin and Vollmecke 1986). According to Rozin, we habituate to commonly eaten foods (the "sensory-specific satiety effect") because our taste preferences, which ensure that we pursue variety, evolved at a time when diets were chemically more diverse than they are today. If so, spice use may function to "trick" our internal mechanisms; by seeming to provide dietary variety, spices encourage consumption of greater quantities of (bland) foods. This hypothesis is intriguing, but it does not predict or explain patterns of spice use demonstrated here, especially relationships with temperature (unless for some reason people in hot climates more frequently experience dietary deficiencies due to sensory-specific satiety).

How do people know what spices to use? We can envision two possibilities. First, people who happened to add spice plants to meat during preparation, especially in hot climates, may have been less likely to suffer from food poisoning or foodborne illnesses than those who did not. Spice users also may have been able to store foods longer before they spoiled, enabling them to tolerate longer periods of scarcity. Observation and imitation of the eating habits of these healthier individuals by others could spread spice use rapidly through a society. Also, families that used appropriate spices would rear more healthy offspring, to whom spice-use traditions had been taught and who possessed appropriate taste receptors. These children would pass to their progeny both the "memes" (Dawkins 1976) for using particular spices and the receptor physiology for tasting them (e.g., Caterina et al. 1997); individual differences in receptor sensitivity to spices are discussed by Drewnowski and Rock (1995) and Tepper and Nurse (1997).

A second possibility involves learned taste aversions. When people eat something that makes them ill, they tend to avoid that taste subsequently (Milgram et al. 1977; Pelchat and Rozin 1982). The adaptive value of such learning is obvious (Letarte et al. 1997). Adding a spice to a food that caused nausea might alter its taste enough to make it palatable again (i.e., it tastes like a different food), as well as kill the microorganisms that caused the illness, thus rendering it safe for consumption. By this process, food aversions would more often be associated with unspiced (and unsafe) foods, and food likings would be associated with spicy foods, especially in places where foods spoil rapidly. Over time, the habit of spicing foods and use of multiple spices in each recipe could become prevalent owing to the iteration of this process (i.e., sequential changes in spices and tastes for them, associated with inhibition of different bacteria and fungi).

Of course, spice use is not the only way to avoid food poisoning and foodborne pathogens. Cooking and completely consuming wild game immediately after slaughter reduces opportunities for microorganismal growth. However, this is practical only where fresh meat is abundant year-round (e.g., Ache hunter-gatherers in Paraguay: Hill et al. 1984). In areas where fresh meat is not consistently available, preservation may be accomplished by thoroughly cooking, salting, smoking, drying, and spicing meats. Indeed, salt has been used worldwide for centuries to preserve food (Alford and Palumbo 1969; Helmy et al. 1985). We hypothesize that all these practices have been adopted for essentially the same reason: to minimize effects of foodborne pathogens.

Our correlational or "forward approach" (Sherman and Reeve 1997) analyses of spice use would be usefully complemented by experimental studies of how the use of different spices and spice combinations affects individual fitness in different countries and cultures (i.e., the "backward approach"). A decisive test of the antimicrobial hypothesis would involve quantifying the frequency of foodborne illnesses, and the survival and reproductive successes of individuals living in the same geographic area and eating essentially the same foods, but using different spices and combinations of them.

In sum, we believe that the probable ultimate reason why humans spice foods is to take advantage of the antimicrobial actions of the plant secondary compounds that give spices their flavors. We hypothesize that, by cleansing foods of pathogens, spice users contribute to their health, survival and reproduction. These then may be the reasons why many people, especially those living in or visiting hot climates, prefer food that is spicy.

ACKNOWLEDGMENTS

For helpful comments during the course of this research we thank the Animal Behavior Lunch Bunch at Cornell University (particularly Peter S Buston, Hamilton E Farris, John M Peters, H Kern Reeve and Philip T Starks), the Museum Lunch Bunch at the University of Michigan (particularly Richard D Alexander, John Cooley, David Marshall and Cynthia Simms Parr), and Thomas A Gavin, Gavin B Grant, Bobbi S Low, Richard D Howard and Deedra K McClearn. For assistance with references we thank the Cornell University Food Science and Nutrition Department, the Cornell College of Human Ecology and the Division of Nutritional Science Statistical Consulting Service, the Cornell University Olin Library Interlibrary Loan Department, and the Circulation and Reference staff at Cornell's Mann and Nestlé Libraries. For comments on preliminary versions of the manuscript we thank Thomas Eisner, Thomas A Gavin, Thomas Neuhaus, Frank A Pitelka, H Kern Reeve, Laurel Southard and Beverly I Strassmann. During the research, JB was partially supported by a Howard Hughes Summer Fellowship administered by Cornell University and PWS was supported by grants from the National Science Foundation and Cornell University.

REFERENCES

Abdou I A, Abou-Zeid A A, El-Sherbeeny M R, Abou-el-Gheat Z H. 1972. Antimicrobial activities of *Allium sativum, Allium cepa, Raphanus sativus, Capsicum frutescens, Eruca sativa, Allium kurrat* on bacteria. *Qualitas Plantarum et Materiae Vegetabiles* 22:29–35.

Ackerman B D, Lindzey F G, Hemker T P. 1984. Cougar food habits in southern Utah. *Journal of Wildlife Management* 48:147–155.

Adam H K. 1967. *The Wine and Food Society's Guide to German Cookery.* Cleveland (OH): World Publishing Company.

Ahmed F H, El-Badri A A, Ibrahim M M K, El-Shahed A S, El-Khalafawy H M M. 1994. Comparative studies of antifungal potentialities for some natural plant oils against different fungi isolated from poultry. *Grasas y Aceites: Revista Bimestra de Informaci on Cientifica y Tecnica* 45:260–264.

Akgul A, Kivanc M. 1988. Inhibitory effects of selected Turkish spices and oregano components on some foodborne fungi. *International Journal of Food Microbiology* 6:263–268.

Aktug S E, Karapinar M. 1986. Sensitivity of some common food-poisoning bacteria to thyme, mint and bay leaves. *International Journal of Food Microbiology* 3:349–354.

Alcock J, Sherman P W. 1994. The utility of the proximate-ultimate dichotomy in ethology. *Ethology* 96:58–62.

Alejandro R. 1982. *The Philippine Cookbook.* New York: Coward-McCann.

Alford J A, Palumbo S A. 1969. Interaction of salt, pH, and temperature on the growth and survival of *Salmonellae* in ground pork. *Applied Microbiology* 17:528–532.

Anderson J. 1986. *The Food of Portugal.* New York: William Morrow.

Anthonio H O, Isoun M. 1982. *Nigerian Cookbook.* London: Macmillan.

Armstrong A. 1986. *The Joyce of Cooking.* New York: Station Hill Press.

Arras G, Grella G E. 1992. Wild thyme, *Thymus capitatus,* essential oil seasonal changes and antimycotic activity. *Journal of Horticultural Science* 67: 197–202.

Aruoma O I, Spencer J P E, Warren D, Jenner P, Butler J, Halliwell B. 1997. Characterization of food antioxidants, illustrated using commercial garlic and ginger preparations. *Food Chemistry* 60:149–156.

Azzouz M A, Bullerman L B. 1982. Comparative antimycotic effects of selected herbs, spices, plant components and commercial antifungal agents. *Journal of Food Protection* 45:1298–1301.

Bachmann F M. 1916. The inhibiting action of certain spices on the growth of microorganisms. *Journal of Industrial and Engineering Chemistry* 8:620–623.

Bair F E, editor. 1992. *The Weather Almanac,* Sixth Edition. Detroit (MI): Gale Research.

Bar-David M L. 1964. *The Israeli Cookbook.* New York: Crown Publishers.

Barker L M, editor. 1982. *The Psychobiology of Human Food Selection.* Westport (CT): AVI Publishing Company.

Barron R. 1991. *Flavors of Greece.* New York: William Morrow.

Batmanglij N. 1992. *New Food of Life: Ancient Persian and Modern Iranian Cooking and Ceremonies.* Washington DC: Mage Publishers.

Bayoumi S. 1992. Bacteriostatic effect of some spices and their utilization in the manufacture of yoghurt. *Chemie Mikrobiologie Technologie der Lebensmittel* 14:21–26.

Beckstrom-Sternberg S M, Duke J A. 1994. Potential for synergistic action of phytochemicals in spices. In *Spices, Herbs, and Edible Fungi,* edited by G Charalambous, pp 201–223. Amsterdam: Elsevier.

Beier R C, Nigg H N. 1994. Toxicology of naturally occurring chemicals in food. In *Foodborne Disease Handbook,* Volume 3: Diseases Caused by Hazardous Substances, edited by Y H Hui, J R Gorham, K D Murrell and D O Cliver, pp 1–186. New York: Marcel Dekker.

Benton P. 1960. *Finnish Food for Your Table.* Oxford (UK): Bruno Cassirer.

Berg E. 1963. *Swedish Foods.* Gothenburg: Wezäta Förlag.

Berg W E, Chesness R A. 1978. Ecology of coyotes in northern Minnesota. In *Coyotes,* edited by M Bekoff, pp 229–247. New York: Academic Press.

Beuchat L R. 1994. Antimicrobial properties of spices and their essential oils. In *Natural Antimicrobial Systems and Food Preservation,* edited by V M Dillon and R G Board, pp 167–179. Wallingford (UK): CAB International.

Beuchat L R, Golden D A. 1989. Antimicrobials occurring naturally in foods. *Food Technology* 43: 134–142.

Blue B A. 1977. *Authentic Mexican Cooking: Auténtica Cocina de Méjico.* Englewood Cliffs (NJ): Prentice-Hall.

Board R G, Gould G W. 1991. Future prospects. In *Food Preservatives,* edited by N J Russell and G W Gould, pp 267–284. Glasgow (UK): Blackie.

Booth I R, Kroll R G. 1989. The preservation of foods by low pH. In *Mechanisms of Action of Food Preservation Procedures,* edited by G W Gould, pp 119–160. London: Elsevier.

Bosland P W. 1994. Chilies: history, cultivation, and uses. In *Spices, Herbs, and Edible Fungi,* edited by

G Charalambous, pp 347–366. Amsterdam: Elsevier.

Bovallius A, Bucht B, Roffey R, Anas P. 1978. Three-year investigation of the natural airborne bacterial flora at four localities in Sweden. *Applied and Environmental Microbiology* 35:847–852.

Boyd L, editor. 1976. *British Cookery: A Complete Guide to Culinary Practice in England, Scotland, Ireland and Wales.* New York: Overlook Press.

Briozzo J, Nunez L, Chirife J, Herszage L, D'Aquino M. 1989. Antimicrobial activity of clove oil dispersed in a concentrated sugar solution. *Journal of Applied Bacteriology* 66:69–75.

Brown E. 1987. *Southwest Tastes.* Tucson (AZ): HP Books.

Brown M H, editor. 1982. *Meat Microbiology.* New York: Elsevier.

Bryan F L. 1988. Risks of practices, procedures, and processes that lead to outbreaks of foodborne diseases. *Journal of Food Protection* 51:663–673.

Bryan F L, Fanelli M J, Riemann H. 1979. *Salmonella* infections. In *Foodborne Infections and Intoxications,* Second Edition, edited by H Riemann and F L Bryan, pp 73–130. New York: Academic Press.

Bugialli G. 1992. *The Fine Art of Italian Cooking,* Second Edition. New York: Times Books.

Butler D. 1996. Novel pathogens beat food safety checks. *Nature* 384:397.

Cameron S M, McDonnell E D, Russell S M, Williams W I. 1980. *Cookery the Australian Way,* Third Edition. South Melbourne: The Macmillan Company of Australia.

Carrier R. 1987. *A Taste of Morocco: A Culinary Journey with Recipes.* New York: Crown Publishers.

Caterina M J, Schumacher M A, Tominaga M, Rosen T A, Levine J D, Julius D. 1997. The capsaicin receptor: a heat-activated ion channel in the pain pathway. *Nature* 389:816–824.

Cavallini P, Volpi T. 1995. Biases in the analysis of the diet of the red fox *Vulpes vulpes. Wildlife Biology* 1:243–248.

Chang W W, Chang I B, Kutscher H W, Kutscher A H. 1982. *An Encyclopedia of Chinese Food and Cooking.* New York: Crown Publishers.

Chaslin P, Canungmai P. 1987. *Discover Thai Cooking.* Singapore: Times Editions.

Chen H C, Chang M D, Chang T J. 1985. Antibacterial properties of some spice plants before and after heat treatment. *Chinese Journal of Microbiology and Immunology* 18:190–195.

Chen S-L. 1988. *Japanese Cuisine.* Monterey Park (CA): Wei-chuan's Cooking.

Chevallier A. 1996. *The Encyclopedia of Medicinal Plants.* New York: DK Publishing.

Cichewicz R H, Thorpe P A. 1996. The antimicrobial properties of chile peppers (*Capsicum* species) and their use in Mayan medicine. *Journal of Ethnopharmacology* 52:61–70.

Claudio V S. 1977. *Philippine Recipes and Typical Menus.* Manila: Merriam School and Office Supplies.

Clayton D H, Wolfe N D. 1993. The adaptive significance of self-medication. *Trends in Ecology & Evolution* 8:60–63.

Cleveland B A. 1952. *Frontier Formulas: An Alaskan Cook Book.* Juneau (AK): Totem Press.

Coe S D. 1994. *America's First Cuisines.* Austin: University of Texas Press.

Conway M, Liston L L, editors. 1990. *The Weather Handbook.* Atlanta: Conway Data.

Czerny Z. 1975. *Polish Cookbook.* Warsaw: Panstwowe Wydawnictwo Ekonomiczne.

Dawkins R. 1976. *The Selfish Gene.* Oxford (UK): Oxford University Press.

Day I F. 1975. *The Moroccan Cookbook.* New York: Quick Fox.

De Andrade M. 1965. *Brazilian Cookery: Traditional and Modern.* Rutland (VT): Charles E. Tuttle.

Deans S G, Ritchie G. 1987. Antibacterial properties of plant essential oils. *International Journal of Food Microbiology* 5:165–180.

Dede A. 1969. *Ghanaian Favorite Dishes.* Accra (Africa): Anowuo Educational Publications.

De' Medici L. 1990. *The Heritage of Italian Cooking.* New York: Random House.

De Villiers S J A. 1961. *Cook and Enjoy It: South African Cookery Manual.* Cape Town (South Africa): Central News Agency.

DeWit A, Borghese A. 1973. *The Complete Book of Indonesian Cooking.* New York: Bobbs-Merrill.

Diebel K E, Banwart G J. 1984. Effect of spices on *Campylobacter jejuni* at three temperatures. *Journal of Food Safety* 6:241–251.

Dillon V M, Board R G, editors. 1994. *Natural Antimicrobial Systems and Food Preservation.* Wallingford (UK): CAB International.

Doyle M P, Cliver D O. 1990. *Salmonella.* In *Foodborne Diseases,* edited by D O Cliver, pp 185–208. New York: Academic Press.

Drewnowski A, Rock C L. 1995. The influence of genetic taste markers on food acceptance. *American Journal of Clinical Nutrition* 62:506–511.

Duke J A. 1994. Biologically active compounds in important spices. In *Spices, Herbs, and Edible Fungi,* edited by G Charalambous, pp 201–223. Amsterdam: Elsevier.

Duong B, Kiesel M. 1991. *The Simple Art of Vietnamese Cooking.* New York: Prentice Hall.

Ehrlich P R, Raven P H. 1964. Butterflies and plants: a study in coevolution. *Evolution* 18:586–608.

El-Kady I A, El-Maraghy S S M, Mostafa M E. 1993. Antibacterial and antidermatophyte activities of some essential oils from spices. *Qatar University Science Journal* 13:63–69.

El-Khateib T, El-Rahman H A. 1987. Effect of garlic and *Lactobacillus plantarum* on growth of *Salmo-*

nella typhimurium in Egyptian fresh sausage and beefburger. *Journal of Food Protection* 50:310–311.

Ember M, Otterbein K F. 1991. Sampling in cross-cultural research. *Behavior Science Research* 25:217–233.

Ensminger A H, Ensminger M E, Konlande J E, Robson J R K. 1983. *Foods and Nutrition Encyclopedia.* Clovis (CA): Pegus Press.

Escudier J N, Fuller P J. 1968. *The Wonderful Food of Provence.* Boston: Houghton Mifflin.

Etkin N L, editor. 1986. *Plants in Indigenous Medicine and Diet: Biobehavioral Approaches.* Bedford Hills (NY): Redgrave Publishing.

Evans A S, Brachman P S, editors. 1991. *Bacterial Infections of Humans: Epidemiology and Control,* Second Edition. New York: Plenum.

Evert Ting W T, Deibel K E. 1992. Sensitivity of *Listeria monocytogenes* to spices at two temperatures. *Journal of Food Safety* 12:129–137.

Farag R S, Daw Z Y, Hewedi F M, El-Baroty G S A. 1989. Antimicrobial activity of some Egyptian spice essential oils. *Journal of Food Protection* 52: 665–667.

Farah M. 1979. *Lebanese Cuisine.* Portland (OR): Lebanese Cuisine Publishers.

Farbrood M I, MacNeil J H, Ostovar K. 1976. Effect of rosemary spice extractive on growth of microorganisms in meats. *Journal of Milk and Food Technology* 39:675–679.

Farrell K T. 1990. *Spices, Condiments, and Seasonings,* Second Edition. New York: Van Nostrand Reinhold.

Ferguson J. 1989. *Flavor of New England.* New York: Mallard Press.

Fernandez R. 1985. *Malaysian Cookery.* New York: Penguin Books.

Ferrari N, Weber J M. 1995. Influence of the abundance of food resources on feeding habits of the red fox, *Vulpes vulpes,* in western Switzerland. *Journal of Zoology* 236:117–129.

Flavor of the South. 1989. New York: Mallard Press.

Fraenkel G S. 1959. The raison d'être of secondary plant substances. *Science* 129:1466–1470.

Galli A, Franzetti L, Briguglio D. 1985. Antimicrobial properties in vitro of essential oils and extracts of spices used for foods. *Industrie Alimentari* 24: 463–466.

Gandi D N, Ghodekar D R. 1988. Antibacterial activity of garlic extract against lactic acid bacteria and contaminants of fermented milks. *Indian Journal of Dairy Science* 41:511–512.

Gardner A. 1993. *Karibu: Welcome to the Cooking of Kenya.* Nairobi (Kenya): Kenway Publications.

Genigeorgis C A. 1981. Factors affecting the probability of growth of pathogenic microorganisms in foods. *Journal of the American Veterinary Medical Association* 179:1410–1417.

Giese J. 1994. Spice and seasoning blends: a taste for all seasons. *Food Technology* 48(4):87–90.

Gilbert R J. 1979. *Bacillus cereus* gastroenteritis. In *Foodborne Infections and Intoxications,* Second Edition, edited by H Riemann and F L Bryan, pp 495–518. New York: Academic Press.

Gill C O, Penny N. 1977. Penetration of bacteria into meat. *Applied Environmental Microbiology* 33: 1284–1286.

Gould G W. 1992. Ecosystems approach to food preservation. In Symposium 21: *Ecosystems, Microbes, Food,* edited by R G Board, D Jones, R G Kroll and G L Pettipher, supplement to *Journal of Applied Bacteriology* 73:58S–68S.

Gould G W, Brown M H, Fletcher B C. 1983. Mechanisms of action of food preservation procedures. In *Food Microbiology: Advances and Prospects,* edited by T A Roberts and F A Skinner, pp 67–84. London: Academic Press.

Govindarajan V S. 1985. Capsicum production, technology, chemistry, and quality. Part I: History, botany, cultivation, and primary processing. *CRC Critical Reviews in Food Science and Nutrition* 22:109–176.

Griffin P M, Tauxe R V. 1991. The epidemiology of infections caused by *Escherichia coli* 0157:H7, other enterohemorrhagic *E. coli* and the associated hemolytic uremic syndrome. *Epidemiologic Reviews* 13:60–98.

Grigson J. 1985. *British Cookery.* New York: Atheneum.

Gugnani H C, Ezenwanze E C. 1985. Antibacterial activity of extracts of ginger *Ginger zingiber* and African oil bean seed *Pentaclethra macrophylla. Journal of Communicable Diseases* 17:233–236.

Hafner D. 1993. *A Taste of Africa.* Berkeley (CA): Ten Speed Press.

Harben A, editor. 1983. *Traditional Malaysian Cuisine.* Kuala Lumpur (Malaysia): Berita Publishing.

Hargreaves L L, Jarvis B, Rawlinson A P, Wood J M. 1975. The antimicrobial effects of spices, herbs and extracts from these and other food plants. *Scientific and Technical Surveys, British Food Manufacturing Industries Research Association* 88:1–56.

Harris M. 1985. *Good to Eat: Riddles of Food and Culture.* New York: Simon and Schuster.

Hartung J. 1982. Polygyny and the inheritance of wealth. *Current Anthropology* 23:1–12.

Hartung J. 1997. If I had it to do over again. In *Human Nature,* edited by L Betzig, pp 344–348. Oxford (UK): Oxford University Press.

Hassan C M, Ahsan M, Islam S K N. 1989. In vitro antibacterial screening of the oils of *Nigella sativa* seeds. *Bangladesh Journal of Botany* 18:171–174.

Hazelton N S. 1964. *The Art of Danish Cooking.* Garden City (NJ): Doubleday.

Hefnawy Y A, Moustafa S I, Marth E H. 1993. Sensitivity of *Listeria monocytogenes* to selected spices. *Journal of Food Protection* 56:876–878.

Hekmat F. 1994. *The Art of Persian Cooking.* New York: Hippocrene Books.

Helmy Z A, Zahra M K, Musleh R M. 1985. Some factors affecting *Salmonellae* growth in meat. *Egyptian Journal of Microbiology* 20:153–164.

Higham M. 1950. *Household Cookery for South Africa.* Cape Town (South Africa): Central News Agency.

Hill K, Hawkes K, Hurtado M, Kaplan H. 1984. Seasonal variance in the diet of Ache hunter-gatherers in eastern Paraguay. *Human Ecology* 12:101–135.

Hinkle D E, Wiersma W, Jurs S G. 1988. *Applied Statistics for the Behavioral Sciences.* Boston: Houghton Mifflin.

Hobbs B C, Roberts D. 1993. *Food Poisoning and Food Hygiene,* Sixth Edition. London: Edward Arnold.

Hoffman C, Evans A C. 1911. The use of spices as preservatives. *Journal of Industrial and Engineering Chemistry* 3:835–838.

Holland B, Welch A A, Unwin I D, Buss D H, Paul A A, Southgate D A T. 1991. *McCance and Widdowson's The Composition of Foods,* Fifth Edition. Suffolk (UK): Richard Clay.

Holmboe B. 1957. *What You Have Eaten in Norway: Popular Norwegian Dishes.* Oslo (Norway): John Griegs Forlag.

Hom K. 1990. *The Taste of China.* New York: Simon and Schuster.

Hornok L, editor. 1992. *Cultivation and Processing of Medicinal Plants.* New York: John Wiley and Sons.

Huffman M A, Wrangham R W. 1994. Diversity of medicinal plant use by chimpanzees in the wild. In *Chimpanzee Cultures,* edited by R W Wrangham, W C McGrew, F B M DeWaal and P G Heltne, pp 129–148. Cambridge (MA): Harvard University Press.

Hughes B G, Lawson L D. 1991. Antimicrobial effects of *Allium sativum* L. (garlic), *Allium ampeloprasum* L. (elephant garlic), and *Allium cepa* L. (onion), garlic compounds and commercial garlic supplement products. *Phytotherapy Research* 5: 154–158.

Huhtanen C N. 1980. Inhibition of *Clostridium botulinum* by spice extracts and aliphatic alcohols. *Journal of Food Protection* 43:195–196.

Hui Y H, Gorham J R, Murrell K D, Cliver D O, editors. 1994. *Foodborne Disease Handbook,* Volume 1: Diseases Caused by Bacteria. New York: Marcel Dekker.

Hyder S. 1976. *Recipes from the Kenya Coast.* Nairobi (Kenya): Longman.

Hylton W H, editor. 1974. *The Rodale Herb Book: How to Use, Grow, and Buy Nature's Miracle Plants.* Emmaus (PA): Rodale Press.

Islam S K N, Ahsan M, Ferdous A J, Faroque A B M. 1990. In vitro antibacterial activities of commonly used spices. *Bangladesh Journal of Botany* 19:99–101.

Ismaiel A A, Pierson M D. 1990a. Inhibition of growth and germination of *Clostridium botulinum* 33A, 40B, and 1623E by essential oil of spices. *Journal of Food Science* 55:1676–1678.

Ismaiel A A, Pierson M D. 1990b. Effect of sodium nitrite and origanum oil on growth and toxin production of *Clostridium botulinum* in TYG broth and ground pork. *Journal of Food Protection* 53:958–960.

Jakobsson O. 1989. *Good Food in Sweden: A Selection of Regional Dishes.* New York: Bergh Publishing.

Janick J, Schery R W, Woods F W, Ruttan V W. 1981. *Plant Science: An Introduction to World Crops.* San Francisco: W. H. Freeman.

Janzen D H. 1978. Complications in interpreting the chemical defenses of trees against tropical arboreal plant-eating vertebrates. In *The Ecology of Arboreal Folivores,* edited by G G Montgomery, pp 73–84. Washington DC: Smithsonian Institution Press.

Jay J M. 1994. Indicator organisms in food. In *Foodborne Disease Handbook,* Volume 1: Diseases Caused by Bacteria, edited by Y H Hui, J R Gorham, K D Murrell and D O Cliver, pp 537–546. New York: Marcel Dekker.

Jay J M, Rivers G M. 1984. Antimicrobial activity of some food flavoring compounds. *Journal of Food Safety* 6:129–139.

Jensen B. 1962. *Take a Silver Dish: A Book of Danish Food with Recipes, Past and Present, Such As Have Delighted Both Danes and Vistors to Denmark.* Copenhagen: Host and Sons Forlag.

Johns T. 1990. *With Bitter Herbs They Shall Eat It: Chemical Ecology and the Origins of Human Diet and Medicine.* Tucson (AZ): University of Arizona Press.

Johns T, Chapman L. 1995. Phytochemicals ingested in traditional diets and medicines as modulators of energy metabolism. *Recent Advances in Phytochemistry* 29:161–188.

Johnson A S, Hale P E, Ford W M, Wentworth J M, French J R, Anderson O F, Pullen G B. 1995. White-tailed deer foraging in relation to successional stage, overstory type and management of southern Appalachian forests. *American Midland Naturalist* 133:18–35.

Johri R K, Zutshi U. 1992. An Ayurvedic formulation 'Trikatu' and its constituents. *Journal of Ethnopharmacology* 37:85–91.

Kan J, Leong C L. 1963. *Eight Immortal Flavors.* Berkeley (CA): Howell-North Books.

Kanemaru K, Miyamoto T. 1990. Inhibitory effects on the growth of several bacteria by brown mustard and allyl isothiocyanate. *Nippon Shokuhin Kogyo Gakkaishi* 37:823–829.

Karousos G, Ware B J, Karousos T H. 1993. *American Regional Cooking for 8 or 50.* New York: John Wiley and Sons.

Kennedy D. 1978. *Recipes from the Regional Cooks of Mexico.* New York: Harper and Row.

Kim K K, Ryeom K. 1979. A study on capsaicin content and antibacterial effects from Korean hot pepper. *Report of NIH* 16:241-244.

Kirschmann J D, Dunne L J. *Nutrition Almanac,* Second Edition. 1984. New York: McGraw-Hill.

Kivanc M, Akgul A. 1986. Antibacterial activities of essential oils from Turkish spices and citrus. *Flavour and Fragrance Journal* 1:175–179.

Kivanc M, Akgul A, Dogan A. 1991. Inhibitory and stimulatory effects of cumin, oregano, and their essential oils on growth and acid production of *Lactobacillus plantarum* and *Leuconostoc mesenteroides. International Journal of Food Microbiology* 13:81–86.

Klimstra W D, Dooley A L. 1990. Foods of the key deer. *Florida Scientist* 53:264–273.

Koo L C. 1984. The use of food to treat and prevent disease in Chinese culture. *Social Science & Medicine* 18:757–766.

Koul O. 1993. Plant allelochemicals and insect control: an antifeedant approach. In *Chemical Ecology of Phytophagous Insects,* edited by T N Ananthakrishnan and A Raman, pp 51–88. New Delhi: Oxford & IBH.

Kowalchik C, Hylton W H. 1987. *Rodale's Illustrated Encyclopedia of Herbs.* Emmaus (PA): Rodale Press.

Kremezi A. 1993. *The Foods of Greece.* New York: Stewart, Tabori, and Chang.

Kubo I, Himejima M, Muroi H. 1991. Antimicrobial activity of flavor components of cardamom *Elattaria cardamomum* (Zingiberaceae) seed. *Journal of Agricultural and Food Chemistry* 39:1984–1986.

Kurita N, Koike S. 1982. Synergistic antimicrobial effect of sodium chloride and essential oil components. *Agricultural and Biological Chemistry* 46:159–165.

Lang G. 1971. *The Cuisine of Hungary.* New York: Atheneum.

Langseth-Christensen L. 1959. *Gourmet's Old Vienna Cookbook: A Viennese Memoir.* New York: Gourmet Distributing.

Lee C B T, Lee A E. 1976. *The Gourmet Chinese Regional Cookbook.* New York: G. P. Putnam's Sons.

Lee W C, Sakai T, Lee M J, Hamakawa M, Lee S M, Lee I M. 1996. An epidemiological study of food poisoning in Korea and Japan. *International Journal of Food Microbiology* 29:141–148.

Letarte A, Dube L, Troche V. 1997. Similarities and differences in affective and cognitive origins of food likings and dislikes. *Appetite* 28:115–129.

Lin R I-S. 1994. Pharmacological properties and medicinal use of pepper (*Piper nigrum* L.). In *Spices, Herbs, and Edible Fungi,* edited by G Charalambous, pp 469–481. Amsterdam: Elsevier.

Liu Z H, Nakano H. 1996. Antibacterial activity of spice extracts against food related bacteria. *Journal of the Faculty of Applied Biological Science Hiroshima University* 35:181–190.

Lo K H C. 1971. *Peking Cooking.* London: Faber and Faber.

Lo K H C. 1979. *Chinese Regional Cooking.* New York: Pantheon.

Loewenfeld C, Back P. 1974. *The Complete Book of Herbs and Spices.* New York: G. P. Putnam's Sons.

Low J. 1982. *Jennie Low's Szechuan Cookbook.* Novato (CA): Presidio Press.

Mace R, Pagel M. 1994. The comparative method in anthropology. *Current Anthropology* 35:549–564.

Mace R, Pagel M. 1997. Tips, branches, and nodes: seeking adaptation through comparative studies. In *Human Nature,* edited by L Betzig, pp 297–310. Oxford (UK): Oxford University Press.

Maehr D S, Brady J R. 1986. Food habits of bobcats *Lynx rufus* in Florida. *Journal of Mammalogy* 67:133–138.

Mark T. 1974. *Greek Islands Cooking.* Boston: Little, Brown and Co.

Martin P, Martin J. 1970. *Japanese Cooking.* New York: Bobbs-Merrill.

Martinez M. 1944. *Las Plantas Medicinales de Mexico.* Mexico: Ediciones Botas.

Mascolo N, Jain R, Jain S C, Capasso F. 1989. Ethnopharmacologic investigation of ginger (*Zingiber officinale*). *Journal of Ethnopharmacology* 27:129–140.

Mayer-Browne E. 1961. *Austrian Cooking for You.* New York: Universe Books.

McKenzie V, Allen J. 1980. *A Look at Yesteryear: Early Australian Cooking.* Sydney: Centennial.

Mei F P. 1978. *Pei Mei's Chinese Cook Book,* Volume I. Taipei: Pei Mei's.

Mesfin D J. 1987. *Exotic Ethiopia Cooking.* Falls Church (VA): Ethiopian Cookbook Enterprise.

Meyer J E. 1918. *The Herbalist.* Glenwood (IL): Meyerbooks.

Michanie S, Bryan F L, Fernandez N M, Vizcarra M M, Taboada P D, Navarros O, Alonso A B, Santillan M L. 1988. Hazard analyses of foods prepared by inhabitants along the Peruvian Amazon River. *Journal of Food Protection* 51:293–302.

Milgram N W, Krames L, Alloway T M, editors. 1977. *Food Aversion Learning.* New York: Plenum Press.

Millon K, Millon M. 1991. *Flavours of Korea.* London: Andre Deutsch.

Milner J A. 1996. Nonnutritive components in foods as modifiers of the cancer process. In *Nutrition and Health: Preventive Nutrition,* edited by A Bendich and R J Deckelbaum, pp 135–152. Totowa (NJ): Humana Press.

Moliterno I B. 1963. *The Brazilian Cook Book.* New York: Charles Frank.

Moore D S, McCabe G P. 1993. *Introduction to the Practice of Statistics.* New York: W. H. Freeman.

Morris H. 1945. *Korean Recipes.* Wichita (KS): Harriett Morris.

Morton J F. 1976. *Herbs and Spices.* New York: Golden Press.

Moyler D A. 1994. Spices—recent advances. In *Spices, Herbs, and Edible Fungi,* edited by G Charalambous, pp 1–71. Amsterdam: Elsevier.

Murdock G P. 1967. Ethnographic atlas: a summary. *Ethnology* 6:109–236.

Murdock G P, White D R. 1969. Standard cross-cultural sample. *Ethnology* 8:329–369.

Muthachen R. 1969. *Indian Regional Recipes.* Bombay: Jaico Publishing.

Nahoum A. 1971. *The Art of Israeli Cooking.* New York: Edrei-Sharon Publications.

Nakatani N. 1994. Antioxidative and antimicrobial constituents of herbs and spices. In *Spices, Herbs, and Edible Fungi,* edited by G Charalambous, pp 251–272. Amsterdam: Elsevier.

Nesse R M, Williams G C. 1994. *Why We Get Sick.* New York: Random House.

Nkanga E J, Uraih N. 1981. Prevalence of *Staphylococcus aureus* in meat samples from traditional markets in Benin City, Nigeria and possible control by use of condiments. *Journal of Food Protection* 44:4–8.

Ngo B, Zimmerman G. 1979. *The Classic Cuisine of Vietnam.* New York: Barron's Educational Series.

Notermans S, Hoogenboom-Verdegaad A. 1992. Existing and emerging foodborne diseases. *International Journal of Food Microbiology* 15:197–205.

Nyaho E C, Amarteifio E, Asare J. 1970. *Ghana Recipe Book.* Tema (Africa): Ghana Publishing.

Olivet Episcopal Church, Woman's Auxiliary. 1960. *Virginia Cookery, Past and Present.* Franconia (VA): Olivet Episcopal Church.

Onawunmi G, Ogunlana E O. 1986. A study of the antibacterial activity of the essential oil of lemon grass (*Cymbopogon citratus*). *International Journal of Crude Drug Research* 24:64–68.

Otterbein K F. 1994. Comment. *Current Anthropology* 35:559–560.

Owen S. 1976. *Indonesian Food and Cookery.* London: Prospect Books.

Pafumi J. 1986. Assessment of the microbiological quality of spices and herbs. *Journal of Food Protection* 49:958–963.

Pandya M. 1980. *Complete Indian Cookbook.* New York: Larousse.

Parker G. 1995. *Eastern Coyote: The Story of Its Success.* Halifax (Nova Scotia): Nimbus Publishing.

Parry J W. 1953. *The Story of Spices.* New York: Chemical Publishers.

Patil V. 1988. *Food Heritage of India.* Bombay: Vakils, Feffer, and Simons.

Pelchat M L, Rozin P. 1982. The special role of nausea in the acquisition of food dislikes by humans. *Appetite* 3:341–351.

Perry L M. 1980. *Medicinal Plants of East and Southeast Asia.* Cambridge (MA): The MIT Press.

Profet M. 1992. Pregnancy sickness as adaptation: a deterrent to maternal ingestion of teratogens. In *The Adapted Mind,* edited by J Barkow, L Cosmides and J Tooby, pp 327–365. New York: Oxford University Press.

Profet M. 1996. *Protecting Your Baby-To-Be.* New York: Addison-Wesley.

Pruthi J S. 1980. *Spices and Condiments: Chemistry, Microbiology, Technology.* New York: Academic Press.

Ramadan F M, El-Zanfaly R T, El-Wakeil F A, Alian A M. 1972. On the antibacterial effects of some essential oils: I. Use of agar diffusion method. *Chemie Mikrobiologie Technologie der Lebensmittel* 1:96–102.

Rees L P, Minney S F, Plummer N T, Slater J H, Skyrme D A. 1993. A quantitative assessment of the antimicrobial activity of garlic (*Allium sativum*). *World Journal of Microbiology & Biotechnology* 9:303–307.

Rice W R. 1989. Analysing tables of statistical tests. *Evolution* 43:223–225.

Ricklefs R E, Starck J M. 1996. Applications of phylogenetically independent contrasts: a mixed progress report. *Oikos* 77:167–172.

Ritzberg C. 1993. *Classical Afrikan Cuisines.* New York: Afrikan World Information Systems.

Rivers J P W, Hill A W. 1971. The antibacterial action of the Ethiopian condiment 'chow.' *Proceedings of the Nutrition Society* 30:77A–80A.

Roberts D. 1990. Trends in food poisoning. *Food Science and Technology Today* 2:28–34.

Robinette W L, Gashwiler J S, Morris O W. 1959. Food habits of the cougar in Utah and Nevada. *Journal of Wildlife Management* 23:261–273.

Rozin P. 1980. Acquisition of food preferences and attitutes to food. *International Journal of Obesity* 4:356–363.

Rozin P. 1982. Human food selection: the interaction of biology, culture, and individual experience. In *The Psychobiology of Human Food Selection,* edited by L M Barker, pp 225–254. Westport (CT): AVI Publishing Company.

Rozin P, Schiller D. 1980. The nature and acquisition of a preference for chili pepper by humans. *Motivation and Emotion* 4:77–100.

Rozin P, Vollmecke T A. 1986. Food likes and dislikes. *Annual Review of Nutrition* 6:433–456.

Ruhlen M. 1987. *A Guide to the World's Languages,* Volume 1: Classification. Stanford (CA): Stanford University Press.

Rusul G, Chun C K, Radu S. 1997. Survival and growth of *Vibrio cholerae* 0139 in selected Malaysian street foods. *Journal of Food Protection* 60: 644–648.

Sahni J. 1980. *Classic Indian Cooking.* New York: William Morrow.

Salloum M. 1992. *A Taste of Lebanon: Cooking Today the Lebanese Way.* New York: Interlink Books.

Salzer U J. 1982. Antimikrobielle Wirkung einiger Gewurzextrakte und Wurzmischungen. *Die Fleischwirtschaft* 62:885–887.

Sarvis S. 1967. *A Taste of Portugal.* New York: Charles Scribner's Sons.

Sato A, Terao M, Honma Y. 1990. Antibacterial action of garlic extract on food poisoning bacteria. *Journal of the Food Hygienic Society of Japan* 31:328–332.

Saxe T G. 1987. Toxicity of medicinal herbal preparations. *American Family Physician* 35:135–142.

Saxena A P, Vyas K M. 1986. Antimicrobial activity of seeds of some ethnomedicinal plants. *Journal of Economic and Taxonomic Botany* 8:291–299.

Scheiper R. 1993. *Hot Spice.* Springfield (NJ): Contact 57, Haarman and Reimer.

Schery R W. 1972. *Plants for Man.* Englewood Cliffs (NJ): Prentice-Hall.

Schrecker E, Schrecker J. 1976. *Mrs. Chiang's Szechwan Cookbook.* New York: Harper and Row.

Schuler E. 1955. *German Cookery.* New York: Crown Publishers.

Shaida M. 1992. *The Legendary Cuisine of Persia.* London: Lieuse Publications.

Shelef L A. 1984. Antimicrobial effects of spices. *Journal of Food Safety* 6:29–44.

Shelef L A, Jyothi E K, Bulgarelli M A. 1984. Growth of enteropathogenic and spoilage bacteria in sage-containing broth and foods. *Journal of Food Science* 49:737–740.

Shelef L A, Naglik O A, Bogen D W. 1980. Sensitivity of some common food-borne bacteria to the spices sage, rosemary, and allspice. *Journal of Food Science* 45:1042–1044.

Sheridan M. 1965. *The Art of Irish Cooking.* New York: Doubleday.

Sherlock M G, Fairley J S. 1993. Seasonal changes in the diet of red deer *Cervus elaphus* in the Connemara National Park. *Biology and Environment* 93B:85–90.

Sherman P W. 1988. The levels of analysis. *Animal Behaviour* 36:616–618.

Sherman P W, Reeve H K. 1997. Forward and backward: alternative approaches to studying human social evolution. In *Human Nature,* edited by L Betzig, pp 147–158. Oxford (UK): Oxford University Press.

Shetty R S, Singhal R S, Kulkarni P R. 1994. Antimicrobial properties of cumin. *World Journal of Microbiology & Biotechnology* 10:232–233.

Shim C-s. 1984. *Korean Recipes.* Seoul: Seoul International Tourist Publishing.

Simoons F J. 1991. *Food in China: A Cultural and Historical Inquiry.* Boca Raton (FL): CRC Press.

Sockett P N. 1995. The epidemiology and costs of diseases of public health significance, in relation to meat and meat products. *Journal of Food Safety* 15:91–112.

Southwest Cooking. 1990. New York: Beekman House.

Stecchini M L, Sarais I, Giavedoni P. 1993. Effect of essential oils on *Aeromonas hydrophila* in a culture medium and in cooked pork. *Journal of Food Protection* 56:406–409.

Sverdrup E. 1962. *Norway's Delight: Dishes and Specialities.* Oslo (Norway): Johan Grundt Tanum Forlag.

Tainter D R, Grenis A T. 1993. *Spices and Seasonings.* New York: VCH Publishers.

Tan S. 1985. *Immigrant Foods: Second Supplement to McCance and Widdowson's The Composition of Foods.* Amsterdam: Elsevier/North Holland.

Tepper B J, Nurse R J. 1997. Fat perception is related to PROP taster status. *Physiology & Behavior* 61:949–954.

Thompson D P. 1989. Fungitoxic activity of essential oil components on food storage fungi. *Mycologia* 81:151–153.

Thompson D P, Cannon C. 1986. Toxicity of essential oils on toxigenic and nontoxigenic fungi. *Bulletin of Environmental Contamination and Toxicology* 36:527–532.

Todd E C D. 1994. Surveillance of foodborne disease. In *Foodborne Disease Handbook,* Volume 1: Diseases Caused by Bacteria, edited by Y H Hui, J R Gorham, K D Murrell and D O Cliver, pp 461–536. New York: Marcel Dekker.

Todd E C D. 1996. Worldwide surveillance of foodborne disease: the need to improve. *Journal of Food Protection* 59:82–92.

Varnam A H, Evans M G. 1991. *Foodborne Pathogens.* London: Mosby-Year Book.

Viherjuuri M, Tanttu A M, Tanttu J. 1974. *Finlandia Gastronomica.* Helsinki: Otava.

Vista Productions. 1978. *The Love of Thai Cooking.* Hong Kong: Vista Productions.

Walker J R L. 1994. Antimicrobial compounds in food plants. In *Natural Antimicrobial Systems and Food Preservation,* edited by V M Dillon and R G Board, pp 181-204. Wallingford (UK): CAB International.

Weathers W W, Siegel R B. 1995. Body size establishes the scaling of avian postnatal metabolic rate: an interspecific analysis using phylogenetically independent contrasts. *Ibis* 137:532–542.

Weigel R M, Weigel M M. 1989. Nausea and vomiting of early pregnancy and pregnancy outcome. A meta-analytical review. *British Journal of Obstetrics and Gynaecology* 96:1312–1318.

Weiss E, Buchan R. 1979. *The Paprikas Weiss Hungarian Cookbook.* New York: William Morrow.

White J. 1993. *Jasper White's Cooking from New England.* New York: Harper Perennial.

Wilkins C. 1994. Paprika chemistry and its relationship to spice quality. In *Spices, Herbs, and Edible Fungi,* edited by G Charalambous, pp 381–410. Amsterdam: Elsevier.

Willan A. 1981. *French Regional Cooking.* New York: William Morrow.

Wilson J. 1990. *Justin Wilson's Homegrown Louisiana Cookin'.* New York: Macmillan.

World Health Report. 1996. *The State of World Health.* Geneva: World Health Organization.

Zaika L L. 1988. Spices and herbs: their antimicrobial activity and its determination. *Journal of Food Safety* 9:97–118.

Zeranski A. 1968. *The Art of Polish Cooking.* Garden City (NJ): Doubleday.

Ziauddin K S, Rao H S, Fairoze N. 1996. Effect of organic acids and spices on quality and shelf-life of meats at ambient temperature. *Journal of Food Science and Technology* 33:255–258.

Zohary D, Hopf M. 1994. *Domestication of Plants in the Old World: The Origin and Spread of Cultivated Plants in West Asia, Europe, and the Nile Valley,* Second Edition. Oxford (UK): Oxford University Press.

APPENDIX A

Bacterial species killed or inhibited in growth by each spice (n=30)

Spice	Bacteria Inhibited	Bacteria Not Inhibited	References
Allspice	*Bacillus subtilis* *Clostridium botulinum* *Escherichia coli* *Listeria monocytogenes* *Serratia marcescens*	None	Hargreaves et al. 1975 Hefnawy et al. 1993 Huhtanen 1980 Shelef et al. 1980
Anise	*Aerobacter aerogenes* *Aeromonas hydrophila* *Flavobacterium suaveolens* *Leuconostoc cremoris* *Staphylococcus albus* *Streptococcus nasik*	*Alcaligenes faecalis* *Brevibacterium linens* *Citrobacter freundii* *Clostridium botulinum* *Clostridium sporogenes* *Erwinia carotovora* *Lactobacillus plantarum* *Micrococcus luteus* *Staphylococcus faecalis* *Streptococcus faecalis* *Yersinia enterocolitica*	Azzouz and Bullerman 1982 Deans and Ritchie 1987 Hargreaves et al. 1975 Huhtanen 1980 Kivanc and Akgul 1986 Ramadan et al. 1972
Basil	*Acinetobacter calcoaceticus* *Alcaligenes faecalis* *Beneckea natriegens* *Citrobacter freundii* *Enterobacter aerogenes* *Erwinia carotovora* *Flavobacterium suaveolens* *Klebsiella pneumoniae* *Leuconostoc cremoris* *Pseudomonas aeruginosa* *Salmonella pullorum* *Serratia marcescens*	*Aeromonas hydrophila* *Bacillus subtilus* *Brevibacterium linens* *Brocothrix thermosphacta* *Clostridium sporogenes* *Escherichia coli* *Lactobacillus plantarum* *Micrococcus luteus* *Proteus vulgaris* *Staphylococcus aureus* *Streptococcus faecalis* *Yersinia enterocolitica*	Deans and Ritchie 1987
Bay Leaves	*Acinetobacter calcoaceticus* *Aeromonas hydrophila* *Alcaligenes faecalis* *Bacillus subtilis* *Beneckea natriegens* *Brocothrix thermosphacta* *Citrobacter freundii* *Clostridium botulinum* *Enterobacter aerogenes* *Erwinia carotovora* *Escherichia coli* *Flavobacterium suaveolens* *Klebsiella pneumoniae* *Lactobacillus plantarum* *Leuconostoc cremoris* *Proteus vulgaris* *Pseudomonas aeruginosa* *Salmonella pullorum* *Serratia marcescens* *Staphylococcus aureus* *Staphylococcus faecalis* *Vibrio parahaemolyticus* *Yersinia enterocolitica*	*Brevibacterium linens* *Clostridium sporogenes* *Micrococcus luteus* *Salmonella typhimurium* *Streptococcus faecalis*	Aktug and Karapinar 1986 Beuchat 1994 Deans and Ritchie 1987 Hargreaves et al. 1975 Huhtanen 1980

APPENDIX A *continuation*

Spice	Bacteria Inhibited	Bacteria Not Inhibited	References
Capsicums (Chilies)	*Bacillus cereus* *Bacillus subtilis* *Sarcina lutea* *Staphylococcus aureus*	*Listeria monocytogenes*	Evert Ting and Deibel 1992 Hargreaves et al. 1975 Hefnawy et al. 1993 Kim and Ryeom 1979
Caraway	*Acinetobacter calcoaceticus* *Aeromonas hydrophila* *Alcaligenes faecalis* *Beneckea natriegens* *Brocothrix thermosphacta* *Citrobacter freundii* *Enterobacter aerogenes* *Erwinia carotovora* *Flavobacterium suaveolens* *Klebsiella pneumoniae* *Leuconostoc cremoris* *Mycobacterium phlei* *Proteus morganii* *Proteus vulgaris* *Pseudomonas fluorescens* *Salmonella enteritidis* *Salmonella pullorum* *Serratia marcescens* *Staphylococcus aureus*	*Brevibacterium linens* *Clostridium botulinum* *Clostridium sporogenes* *Lactobacillus plantarum* *Micrococcus luteus* *Staphylococcus faecalis* *Streptococcus faecalis* *Yersinia enterocolitica*	Deans and Ritchie 1987 Farag et al. 1989 Hargreaves et al. 1975 Huhtanen 1980 Ramadan et al. 1972
Cardamom	*Aeromonas hydrophila* *Bacillus anthracis* *Bacillus cereus* *Brocothrix thermosphacta* *Flavobacterium suaveolens* *Lactobacillus bulgaricus* *Leuconostoc cremoris* *Micrococcus (Sarcina)* *Pseudomonas fluorescens* *Pseudomonas pyocyanea* *Salmonella paratyphi* *Serratia rhadnii* *Streptococcus thermophilus*	*Acinetobacter calcoaceticus* *Alcaligenes faecalis* *Beneckea natriegens* *Brevibacterium linens* *Citrobacter freundii* *Clostridium sporogenes* *Erwinia carotovora* *Lactobacillus plantarum* *Micrococcus luteus* *Salmonella pullorum* *Serratia marcescens* *Streptococcus faecalis* *Streptococcus nasik* *Yersinia enterocolitica*	Azzouz and Bullerman 1982 Bayoumi 1992 Deans and Ritchie 1987 El-Kady et al. 1993 Islam et al. 1990 Kubo et al. 1991
Celery Seed	*Aerobacter aerogenes* *Bacillus subtilis* *Brocothrix thermosphacta* *Clostridium botulinum* *Flavobacterium suaveolens* *Leuconostoc cremoris* *Staphylococcus albus* *Staphylococcus aureus*	*Acinetobacter calcoaceticus* *Aeromonas hydrophila* *Alcaligenes faecalis* *Bacillus cereus* *Beneckea natriegens* *Brevibacterium linens* *Citrobacter freundii* *Clostridium sporogenes* *Enterobacter aerogenes* *Erwinia carotovora* *Klebsiella pneumoniae* *Lactobacillus plantarum* *Micrococcus luteus* *Salmonella pullorum* *Serratia marcescens* *Staphylococcus faecalis* *Streptococcus faecalis* *Yersinia enterocolitica*	Deans and Ritchie 1987 Huhtanen 1980 Kivanc and Akgul 1986 Ramadan et al. 1972

APPENDIX A *continuation*

Spice	Bacteria Inhibited	Bacteria Not Inhibited	References
Cinnamon	*Acinetobacter calcoaceticus* *Aeromonas hydrophila* *Alcaligenes faecalis* *Bacillus anthracis* *Bacillus cereus* *Bacillus subtilis* *Beneckea natriegens* *Brevibacterium linens* *Brocothrix thermosphacta* *Citrobacter freundii* *Erwinia carotovora* *Escherichia coli* *Flavobacterium suaveolens* *Lactobacillus bulgaricus* *Lactobacillus plantarum* *Leuconostoc cremoris* *Listeria monocytogenes* *Micrococcus luteus* *Proteus vulgaris* *Pseudomonas fluorescens* *Pseudomonas pyocyanea* *Salmonella paratyphi* *Salmonella pullorum* *Serratia marcescens* *Serratia rhadnii* *Staphylococcus aureus* *Streptococcus nasik* *Streptococcus thermophilus* *Yersinia enterocolitica*	*Clostridium sporogenes* *Enterobacter aerogenes* *Pseudomonas aeruginosa* *Streptococcus faecalis*	Azzouz and Bullerman 1982 Bayoumi 1992 Beuchat 1994 Deans and Ritchie 1987 El-Kady et al. 1993 Evert Ting and Deibel 1992 Hargreaves et al. 1975 Huhtanen 1980 Islam et al. 1990 Ismaiel and Pierson 1990a Shelef et al. 1984 Zaika 1988
Cloves	*Acinetobacter calcoaceticus* *Aeromonas hydrophila* *Bacillus anthracis* *Bacillus cereus* *Bacillus subtilis* *Beneckea natriegens* *Citrobacter freundii* *Clostridium botulinum* *Clostridium perfringens* *Enterobacter aerogenes* *Erwinia carotovora* *Escherichia coli* *Flavobacterium suaveolens* *Klebsiella pneumoniae* *Lactobacillus bulgaricus* *Lactobacillus plantarum* *Leuconostoc cremoris* *Listeria monocytogenes* *Micrococcus luteus* *Mycobacterium phlei* *Proteus morganii* *Proteus vulgaris* *Pseudomonas aeruginosa* *Pseudomonas fluorescens* *Salmonella enteritidis*	*Clostridium sporogenes* *Micrococcus (Sarcina)* *Pseudomonas pyocyanea* *Salmonella paratyphi* *Serratia rhadnii*	Azzouz and Bullerman 1982 Bayoumi 1992 Beuchat 1994 Briozzo et al. 1989 Deans and Ritchie 1987 El-Kady et al. 1993 Evert Ting and Deibel 1992 Farag et al. 1989 Hargreaves et al. 1975 Huhtanen 1980 Ismaiel and Pierson 1990a Jay and Rivers 1984 Ramadan et al. 1972 Shelef et al. 1984 Stecchini et al. 1993 Zaika 1988

APPENDIX A *continuation*

Spice	Bacteria Inhibited	Bacteria Not Inhibited	References
Cloves *(continuation)*	*Salmonella pullorum* *Serratia marcescens* *Staphylococcus aureus* *Streptococcus faecalis* *Streptococcus nasik* *Streptococcus thermophilus* *Yersinia enterocolitica*		
Coriander	*Aerobacter aerogenes* *Aeromonas hydrophila* *Bacillus subtilis* *Brocothrix thermosphacta* *Citrobacter freundii* *Enterobacter aerogenes* *Erwinia carotovora* *Escherichia coli* *Flavobacterium suaveolens* *Klebsiella pneumoniae* *Lactobacillus plantarum* *Leuconostoc cremoris* *Staphylococcus albus* *Staphylococcus aureus*	*Acinetobacter calcoaceticus* *Alcaligenes faecalis* *Beneckea natriegens* *Brevibacterium linens* *Clostridium sporogenes* *Micrococcus luteus* *Proteus vulgaris* *Salmonella pullorum* *Serratia marcescens* *Staphylococcus faecalis* *Streptococcus faecalis* *Yersinia enterocolitica*	Deans and Ritchie 1987 Hargreaves et al. 1975 Huhtanen 1980 Kivanc and Akgul 1986 Stecchini et al. 1993
Cumin	*Aerobacter aerogenes* *Bacillus anthracis* *Bacillus cereus* *Bacillus coagulans* *Bacillus subtilis* *Clostridium botulinum* *Enterobacter aerogenes* *Lactobacillus plantarum* *Leuconostoc mesenteroides* *Listeria monocytogenes* *Micrococcus (Sarcina)* *Proteus vulgaris* *Pseudomonas aeruginosa* *Pseudomonas fluorescens* *Salmonella enteritidis* *Salmonella paratyphi* *Serratia marcescens* *Staphylococcus albus* *Staphylococcus aureus* *Streptococcus faecalis* *Streptococcus nasik*	*Klebsiella pneumoniae* *Pseudomonas pyocyanea* *Serratia rhadnii*	Azzouz and Bullerman 1982 El-Kady et al. 1993 Farag et al. 1989 Hassan et al. 1989 Hefnawy et al. 1993 Huhtanen 1980 Kivanc and Akgul 1986 Kivanc et al. 1991 Ramadan et al. 1972 Saxena and Vyas 1986 Shetty et al. 1994
Dill	*Acinetobacter calcoaceticus* *Aerobacter aerogenes* *Aeromonas hydrophila* *Brevibacterium linens* *Citrobacter freundii* *Enterobacter aerogenes* *Erwinia carotovora* *Flavobacterium suaveolens* *Klebsiella pneumoniae* *Proteus vulgaris* *Pseudomonas aeruginosa* *Serratia marcescens* *Staphylococcus albus* *Staphylococcus aureus*	*Alcaligenes faecalis* *Beneckea natriegens* *Brocothrix thermosphacta* *Clostridium botulinum* *Clostridium sporogenes* *Lactobacillus plantarum* *Leuconostoc cremoris* *Micrococcus luteus* *Salmonella pullorum* *Staphylococcus faecalis* *Streptococcus faecalis* *Yersinia enterocolitica*	Deans and Ritchie 1987 Hargreaves et al. 1975 Huhtanen 1980 Kivanc and Akgul 1986 Ramadan et al. 1972

APPENDIX A *continuation*

Spice	Bacteria Inhibited	Bacteria Not Inhibited	References
Fennel	*Aerobacter aerogenes*	*Alcaligenes faecalis*	Deans and Ritchie 1987
	Bacillus cereus	*Beneckea natriegens*	Hargreaves et al. 1975
	Bacillus subtilis	*Brevibacterium linens*	Huhtanen 1980
	Citrobacter freundii	*Brocothrix thermosphacta*	Kivanc and Akgul 1986
	Enterobacter aerogenes	*Clostridium botulinum*	Ramadan et al. 1972
	Erwinia carotovora	*Clostridium sporogenes*	
	Flavobacterium suaveolens	*Klebsiella pneumoniae*	
	Leuconostoc cremoris	*Lactobacillus plantarum*	
	Proteus vulgaris	*Micrococcus luteus*	
	Salmonella enteritidis	*Staphylococcus faecalis*	
	Salmonella pullorum	*Yersinia enterocolitica*	
	Serratia marcescens		
	Staphylococcus albus		
	Staphylococcus aureus		
Garlic	*Bacillus cereus*	None	Abdou et al. 1972
	Bacillus subtilis		Beuchat 1994
	Campylobacter jejuni		El-Khateib and El-Rahman 1987
	Clostridium perfringens		Evert Ting and Deibel 1992
	Enterobacter cloacae		Gandi and Ghodekar 1988
	Enterococcus faecalis		Hargreaves et al. 1975
	Enterococcus faecium		Hefnawy et al. 1993
	Escherichia coli		Hughes and Lawson 1991
	Klebsiella aerogenes		Huhtanen 1980
	Klebsiella pneumoniae		Ismaiel and Pierson 1990b
	Lactobacillus acidophilus		Rees et al. 1993
	Lactobacillus plantarum		Sato et al. 1990
	Listeria monocytogenes		Shelef 1984
	Pediococcus pentosaceus		
	Proteus mirabilis		
	Proteus morganii		
	Proteus vulgaris		
	Pseudomonas aeruginosa		
	Pseudomonas fluorescens		
	Salmonella dublin		
	Salmonella enteritidis		
	Salmonella typhimurium		
	Serratia marcescens		
	Staphylococcus aureus		
	Staphylococcus epidermidis		
	Streptococcus agalactiae		
	Vibrio mimicus		
	Vibrio parahaemolyticus		
	Yersinia enterocolitica		
Ginger	*Bacillus anthracis*	*Acinetobacter calcoaceticus*	Azzouz and Bullerman 1982
	Bacillus subtilis	*Aeromonas hydrophila*	Deans and Ritchie 1987
	Brocothrix thermosphacta	*Alcaligenes faecalis*	Gugnani and Ezenwanze 1985
	Flavobacterium suaveolens	*Beneckea natriegens*	Huhtanen 1980
	Leuconostoc cremoris	*Brevibacterium linens*	Mascolo et al. 1989
	Proteus mirabilis	*Citrobacter freundii*	
	Salmonella typhimurium	*Clostridium sporogenes*	
	Staphylococcus epidermidis	*Enterobacter aerogenes*	
	Staphylococcus haemolyticus	*Erwinia carotovora*	
	Streptococcus viridans	*Klebsiella pneumoniae*	

APPENDIX A *continuation*

Spice	Bacteria Inhibited	Bacteria Not Inhibited	References
Ginger *(continuation)*		*Lactobacillus plantarum* *Micrococcus luteus* *Pseudomonas aeruginosa* *Salmonella pullorum* *Serratia marcescens* *Streptococcus faecalis* *Streptococcus nasik* *Yersinia enterocolitica*	
Lemon	*Aerobacter aerogenes* *Bacillus subtilis* *Brocothrix thermosphacta* *Flavobacterium suaveolens* *Leuconostoc cremoris* *Staphylococcus albus* *Staphylococcus aureus*	*Aeromonas hydrophila* *Alcaligenes faecalis* *Beneckea natriegens* *Brevibacterium linens* *Citrobacter freundii* *Clostridium sporogenes* *Enterobacter aerogenes* *Erwinia carotovora* *Klebsiella pneumoniae* *Lactobacillus plantarum* *Micrococcus luteus* *Salmonella pullorum* *Serratia marcescens* *Staphylococcus faecalis* *Streptococcus faecalis* *Yersinia enterocolitica*	Deans and Ritchie 1987 Kivanc and Akgul 1986
Lemongrass	*Bacillus cereus* *Bacillus subtilis* *Escherichia coli* *Pseudomonas aeruginosa* *Salmonella enteritidis* *Staphylococcus aureus*	*Streptococcus faecalis*	Onawunmi and Ogunlana 1986 Ramadan 1972
Lime	*Aeromonas hydrophila* *Brocothrix thermosphacta* *Flavobacterium suaveolens* *Leuconostoc cremoris*	*Acinetobacter calcoaceticus* *Alcaligenes faecalis* *Bacillus subtilis* *Beneckea natriegens* *Brevibacterium linens* *Citrobacter freundii* *Clostridium sporogenes* *Enterobacter aerogenes* *Erwinia carotovora* *Escherichia coli* *Klebsiella pneumoniae* *Lactobacillus plantarum* *Micrococcus luteus* *Proteus vulgaris* *Pseudomonas aeruginosa* *Salmonella pullorum* *Serratia marcescens* *Staphylococcus faecalis* *Streptococcus faecalis* *Yersinia enterocolitica*	Deans and Ritchie 1987 Kivanc and Akgul 1986

APPENDIX A *continuation*

Spice	Bacteria Inhibited	Bacteria Not Inhibited	References
Majoram	*Acinetobacter calcoaceticus*	*Clostridium sporogenes*	Deans and Ritchie 1987
	Aeromonas hydrophila	*Lactobacillus plantarum*	El-Kady et al. 1993
	Alcaligenes faecalis	*Leuconostoc cremoris*	Hargreaves et al. 1975
	Bacillus anthracis	*Micrococcus luteus*	Ramadan 1972
	Bacillus cereus	*Pseudomonas aeruginosa*	
	Bacillus subtilis	*Salmonella paratyphi*	
	Beneckea natriegens	*Serratia rhadnii*	
	Brevibacterium linens	*Yersinia enterocolitica*	
	Brocothrix thermosphacta		
	Citrobacter freundii		
	Enterobacter aerogenes		
	Erwinia carotovora		
	Escherichia coli		
	Flavobacterium suaveolens		
	Klebsiella pneumoniae		
	Micrococcus (Sarcina)		
	Proteus vulgaris		
	Pseudomonas fluorescens		
	Pseudomonas pyocyanea		
	Salmonella enteritidis		
	Salmonella pullorum		
	Serratia marcescens		
	Staphylococcus aureus		
	Streptococcus faecalis		
Mint	*Acinetobacter calcoaceticus*	*Alcaligenes faecalis*	Aktug and Karapinar 1986
	Aeromonas hydrophila	*Brevibacterium linens*	Bayoumi 1992
	Bacillus subtilis	*Erwinia carotovora*	Beuchat 1994
	Beneckea natriegens	*Flavobacterium suaveolens*	Deans and Ritchie 1987
	Brocothrix thermosphacta	*Lactobacillus bulgaricus*	El-Kady et al. 1993
	Citrobacter freundii	*Leuconostoc cremoris*	
	Clostridium sporogenes	*Micrococcus luteus*	
	Enterobacter aerogenes	*Salmonella typhimurium*	
	Escherichia coli	*Staphylococcus aureus*	
	Klebsiella pneumoniae	*Streptococcus thermophilus*	
	Lactobacillus plantarum		
	Proteus vulgaris		
	Pseudomonas aeruginosa		
	Salmonella pullorum		
	Serratia marcescens		
	Streptococcus faecalis		
	Yersinia enterocolitica		
Mustard	*Escherichia coli*	*Clostridium botulinum*	Azzouz and Bullerman 1982
	Proteus vulgaris	*Listeria monocytogenes*	Evert Ting and Deibel 1992
	Pseudomonas aeruginosa		Hargreaves et al. 1975
	Pseudomonas fragi		Huhtanen 1980
	Staphylococcus aureus		Kanemaru and Miyamoto 1990
	Streptococcus nasik		
Nutmeg	*Aeromonas hydrophila*	*Acinetobacter calcoaceticus*	Deans and Ritchie 1987
	Bacillus subtilis	*Alcaligenes faecalis*	Evert Ting and Deibel 1992
	Brevibacterium linens	*Beneckea natriegens*	Hargreaves et al. 1975
	Brocothrix thermosphacta	*Clostridium sporogenes*	Hefnawy et al. 1993
	Citrobacter freundii	*Enterobacter aerogenes*	Huhtanen 1980
	Clostridium botulinum	*Klebsiella pneumoniae*	Stecchini et al. 1993

APPENDIX A *continuation*

Spice	Bacteria Inhibited	Bacteria Not Inhibited	References
Nutmeg	*Erwinia carotovora*	*Lactobacillus plantarum*	
(continuation)	*Escherichia coli*	*Micrococcus luteus*	
	Flavobacterium suaveolens	*Pseudomonas aeruginosa*	
	Leuconostoc cremoris	*Salmonella pullorum*	
	Listeria monocytogenes	*Staphylococcus aureus*	
	Proteus vulgaris	*Streptococcus faecalis*	
	Serratia marcescens		
	Yersinia enterocolitica		
Onion	*Escherichia coli*	None	Abdou et al. 1972
	Salmonella typhimurium		Beuchat 1994
	Shigella dysenteriae		Hargreaves et al. 1975
	Staphylococcus aureus		Hughes and Lawson 1991
			Huhtanen 1980
			Shelef 1984
Oregano	*Aerobacter aerogenes*	None	Beuchat 1994
	Bacillus subtilis		Evert Ting and Deibel 1992
	Clostridium botulinum		Huhtanen 1980
	Escherichia coli		Ismaiel and Pierson 1990a,b
	Lactobacillus plantarum		Kivanc and Akgul 1986
	Leuconostoc mesenteroides		Kivanc et al. 1991
	Listeria monocytogenes		Shelef 1984
	Proteus vulgaris		
	Pseudomonas aeruginosa		
	Staphylococcus albus		
	Staphylococcus aureus		
Parsley	*Acinetobacter calcoaceticus*	*Aeromonas hydrophila*	Deans and Ritchie 1987
	Aerobacter aerogenes	*Alcaligenes faecalis*	Evert Ting and Deibel 1992
	Beneckea natriegens	*Brevibacterium linens*	Kivanc and Akgul 1986
	Citrobacter freundii	*Brocothrix thermosphacta*	Huhtanen 1980
	Enterobacter aerogenes	*Clostridium botulinum*	
	Flavobacterium suaveolens	*Clostridium sporogenes*	
	Klebsiella pneumoniae	*Erwinia carotovora*	
	Salmonella pullorum	*Lactobacillus plantarum*	
	Serratia marcescens	*Leuconostoc cremoris*	
	Staphylococcus albus	*Listeria monocytogenes*	
	Staphylococcus aureus	*Micrococcus luteus*	
	Streptococcus faecalis	*Yersinia enterocolitica*	
Pepper	*Aeromonas hydrophila*	*Acinetobacter calcoaceticus*	Abdou et al. 1972
	Bacillus subtilis	*Alcaligenes faecalis*	Azzouz and Bullerman 1982
	Brocothrix thermosphacta	*Beneckea natriegens*	Deans and Ritchie 1987
	Clostridium botulinum	*Brevibacterium linens*	Evert Ting and Deibel 1992
	Erwinia carotovora	*Citrobacter freundii*	Hefnawy et al. 1993
	Flavobacterium suaveolens	*Clostridium sporogenes*	Huhtanen 1980
	Lactobacillus micrococcus	*Enterobacter aerogenes*	Islam et al. 1990
	Leuconostoc cremoris	*Klebsiella pneumoniae*	Shelef 1984
	Streptococcus nasik	*Lactobacillus plantarum*	Stecchini et al. 1993
	Yersinia enterocolitica	*Micrococcus luteus*	
		Proteus vulgaris	
		Pseudomonas aeruginosa	
		Salmonella pullorum	
		Serratia marcescens	
		Staphylococcus faecalis	
		Streptococcus faecalis	

APPENDIX A *continuation*

Spice	Bacteria Inhibited	Bacteria Not Inhibited	References
Rosemary	*Acinetobacter calcoaceticus* *Aerobacter aerogenes* *Aeromonas hydrophila* *Bacillus anthracis* *Bacillus cereus* *Bacillus megaterium* *Bacillus subtilis* *Beneckea natriegens* *Citrobacter freundii* *Clostridium botulinum* *Clostridium sporogenes* *Flavobacterium suaveolens* *Klebsiella pneumoniae* *Listeria monocytogenes* *Micrococcus (Sarcina)* *Mycobacterium phlei* *Proteus vulgaris* *Pseudomonas fluorescens* *Pseudomonas pyocyanea* *Salmonella paratyphi* *Salmonella pullorum* *Salmonella typhimurium* *Serratia marcescens* *Serratia rhadnii* *Staphylococcus albus* *Staphylococcus aureus* *Staphylococcus epidermidis* *Vibrio parahaemolyticus*	*Alcaligenes faecalis* *Brevibacterium linens* *Brocothrix thermosphacta* *Erwinia carotovora* *Lactobacillus plantarum* *Leuconostoc cremoris* *Micrococcus luteus* *Yersinia enterocolitica*	Beuchat 1994 Deans and Ritchie 1987 El-Kady et al. 1993 Evert Ting and Deibel 1992 Farag et al. 1989 Farbrood et al. 1976 Hargreaves et al. 1975 Huhtanen 1980 Kivanc and Akgul 1986 Shelef 1984 Shelef et al. 1980
Sage	*Aerobacter aerogenes* *Bacillus cereus* *Bacillus megaterium* *Bacillus subtilis* *Beneckea natriegens* *Clostridium botulinum* *Enterobacter aerogenes* *Flavobacterium suaveolens* *Listeria monocytogenes* *Mycobacterium phlei* *Pseudomonas fluorescens* *Staphylococcus aureus* *Staphylococcus epidermidis* *Salmonella pullorum* *Salmonella typhimurium* *Serratia marcescens* *Staphylococcus albus* *Streptococcus nasik* *Vibrio parahaemolyticus*	*Acinetobacter calcoaceticus* *Aeromonas hydrophila* *Alcaligenes faecalis* *Brevibacterium linens* *Brocothrix thermosphacta* *Citrobacter freundii* *Clostridium sporogenes* *Erwinia carotovora* *Klebsiella pneumoniae* *Lactobacillus plantarum* *Leuconostoc cremoris* *Micrococcus luteus* *Yersinia enterocolitica*	Azzouz and Bullerman 1982 Beuchat 1994 Deans and Ritchie 1987 Evert Ting and Deibel 1992 Farag et al. 1989 Hargreaves et al. 1975 Hefnawy et al. 1993 Huhtanen 1980 Kivanc and Akgul 1986 Shelef et al. 1980 Shelef 1984
Tarragon	*Aerobacter aerogenes* *Bacillus subtilis* *Escherichia coli* *Proteus vulgaris* *Pseudomonas aeruginosa* *Staphylococcus aureus* *Staphylococcus albus*	*Clostridium botulinum*	Huhtanen 1980 Kivanc and Akgul 1986

APPENDIX A *continuation*

Spice	Bacteria Inhibited	Bacteria Not Inhibited	References
Thyme	*Acinetobacter calcoaceticus*	*Clostridium sporogenes*	Aktug and Karapinar 1986
	Aerobacter aerogenes	*Leuconostoc cremoris*	Arras and Grella 1992
	Aeromonas hydrophila	*Pseudomonas pyocyanea*	Azzouz and Bullerman 1982
	Alcaligenes faecalis		Beuchat 1994
	Bacillus anthracis		Deans and Ritchie 1987
	Bacillus cereus		El-Kady et al. 1993
	Bacillus subtilis		Farag et al. 1989
	Beneckea natriegens		Huhtanen 1980
	Brevibacterium linens		Ismaiel and Pierson 1990a
	Brocothrix thermosphacta		Kivanc and Akgul 1986
	Citrobacter freundii		Shelef 1984
	Enterobacter aerogenes		
	Erwinia carotovora		
	Escherichia coli		
	Flavobacterium suaveolens		
	Klebsiella pneumoniae		
	Lactobacillus plantarum		
	Micrococcus (Sarcina)		
	Micrococcus luteus		
	Mycobacterium phlei		
	Proteus vulgaris		
	Pseudomonas aeruginosa		
	Pseudomonas fluorescens		
	Salmonella paratyphi		
	Salmonella pullorum		
	Salmonella typhimurium		
	Serratia marcescens		
	Serratia rhadnii		
	Staphylococcus albus		
	Staphylococcus aureus		
	Staphylococcus faecalis		
	Streptococcus faecalis		
	Streptococcus nasik		
	Vibrio parahaemolyticus		
	Yersinia enterocolitica		

APPENDIX B

The 30 species of bacteria used to estimate mean proportion of bacteria inhibited per recipe (see Figure 9)

Bacterial Species

Acinetobacter calcoaceticus
Aerobacter aerogenes
Aeromonas hydrophila
Alcaligenes faecalis
Bacillus cereus
Bacillus subtilis
Beneckea natriegens
Brevibacterium linens
Brocothrix thermosphacta
Citrobacter freundii
Clostridium botulinum
Clostridium sporogenes
Enterobacter aerogenes
Erwinia carotovora
Escherichia coli
Flavobacterium suaveolens
Klebsiella pneumoniae
Lactobacillus plantarum
Leuconostoc cremoris
Listeria monocytogenes
Micrococcus luteus
Proteus vulgaris
Pseudomonas aeruginosa
Salmonella pullorum
Serratia marcescens
Staphylococcus albus
Staphylococcus aureus
Staphylococcus faecalis
Streptococcus faecalis
Yersinia enterocolitica

References

Abdou et al. 1972
Ahmed et al. 1994
Aktug and Karapinar 1986
Arras et al. 1992
Azzouz and Bullerman 1982
Bayoumi 1992
Beuchat 1994
Briozzo et al. 1989
Deans and Ritchie 1987
El-Kady et al. 1993
El-Khateib and El-Rahman 1987
Evert Ting and Deibel 1992
Farag et al. 1989
Farbrood et al. 1976
Gandi and Ghodekar 1988
Gugnani and Ezenwanze 1985
Hargreaves et al. 1975
Hassan et al. 1989
Hefnawy et al. 1993
Hughes and Lawson 1991
Huhtanen 1980
Islam et al. 1990
Ismaiel and Pierson 1990a,b
Jay and Rivers 1984
Kanemaru and Miyamoto 1990
Kim and Ryoem 1979
Kivanc et al. 1991
Kivanc and Akgul 1986
Kubo et al. 1991
Mascolo et al. 1989
Onawunmi and Ogunlana 1986
Ramadan 1972
Rees et al. 1993
Sato et al. 1990
Saxena and Vyas 1986
Shelef 1984
Shelef et al. 1980
Shetty et al. 1984
Stecchini et al. 1993
Zaika 1988