10
Conclusion and Summary

10.1 SUMMARY

The main aim of the thesis was to conduct a computational gastronomic investigation of traditional recipes of Indian Cuisine and explore the health benefits of its central ingredients, spices. One of the broad questions the thesis sought to answer was to uncover the rationale behind the combination of ingredients to form an acceptable and palatable recipe. Towards this goal, the thesis analyzed the food pairing principle based on over 2400 traditional recipes in India Cuisine. Further, we also conducted individual food pairing analysis for eight of its regional cuisines. Our study revealed a negative/contrasting food pairing in Indian Cuisine as opposed to the positive/uniform food pairing trend witnessed in North and Latin American as well as Western European Cuisines. The analysis suggested that the use of spices as a category and individually in traditional Indian recipes greatly influenced the way other ingredients are combined. The thesis compiled a vast repertoire of flavor compounds hitherto available for noncommercial use. This paves the way toward the investigation of flavor compounds. The major conclusion from the study is that culinary spices and herbs form the fulcrum of food pairing in traditional Indian recipes.

Previous research has shown that spices have a wide range of health benefits. They have been shown to be beneficial against cancers, neurodegenerative diseases such as Alzheimer's and Parkinson's disease [Srinivasan 2005]. Incidentally, a major portion of these spices are used as a part of daily culinary preparations in cuisines across the globe, especially in Indian cuisine. We carried out a data-driven analysis of the overall health effects of culinary spices and herbs including their adverse effects. Our text mining study of the health effects of culinary spices and herbs revealed their broad-spectrum therapeutic nature. The study devised a metric to recommend relevant culinary spice and herbs for specific disease categories based on their relative beneficial and adverse effects. Further, the molecular basis for the therapeutic effect of spices is explained by integrating the data on spice-phytochemical as well as phytochemical-disease information. Finally, the results from our studies are compiled and presented as an open-source database, SpiceRx.

10.2 CONCLUDING REMARKS

The methods and results presented in this thesis are of value to food and flavor researchers/industry and healthcare professionals alike. Overall, the thesis presents advancement for further research in the field of computational gastronomy. Our study reveals the culinary fingerprints of recipes in Indian Cuisine and has the potential to be extended into research in the area of nutritional genomics. The databases built as part of the thesis fills a major limitation of lack of integration of data both in the field of flavors as well as the therapeutic effects of spices. The study could potentially lead to methods for creating novel signature recipes in Indian Cuisine and healthier recipe alterations and recipe recommender systems. Our findings can be used in drug discovery and other allied fields for shortlisting candidates for new drugs as well as neutraceuticals.

The results presented in the thesis are subject to certain auxiliary notions considered at the time of study and can change, if not drastically, by a change of these conditions. While studying food pairing in Indian Cuisine, we considered the data available for flavor compounds of ingredients in Indian recipes, which is in no way complete. The data of the flavor compound composition of each ingredient itself may vary while maintaining the generic profile. More experimental studies are required to create an accurate and comprehensive flavor profile of the ingredients. Similarly, the flavor profile of some of the exotic ingredients unique to the cuisine are missing from the current analysis. Even though the thesis throws light on the vital relationship between recipes and ingredients in them, major elements of cooking, such as the method of preparation as well as the quantity of the ingredient was omitted. Cooking itself changes the flavor composition subject and has a component of synergistic effect which too was not accounted in this thesis. Another key dimension that the thesis did not focus on was the intimate connection between food and nutrition.

The data of the spice-disease associations are subject to the accuracy of the association model and information provided in source research articles. Although we have manually checked and corrected the data of negative associations, the same cannot be said of positive associations, which are way too numerous and hence, model-based predictions were made.

In summary, notwithstanding some of the shortcomings mentioned, we believe that studies carried out in the thesis will provide a strong impetus for data-centric investigations of food, flavor and health, and their related applications.

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Supplementary Figures and Data for Chapter 4 and Chapter 5
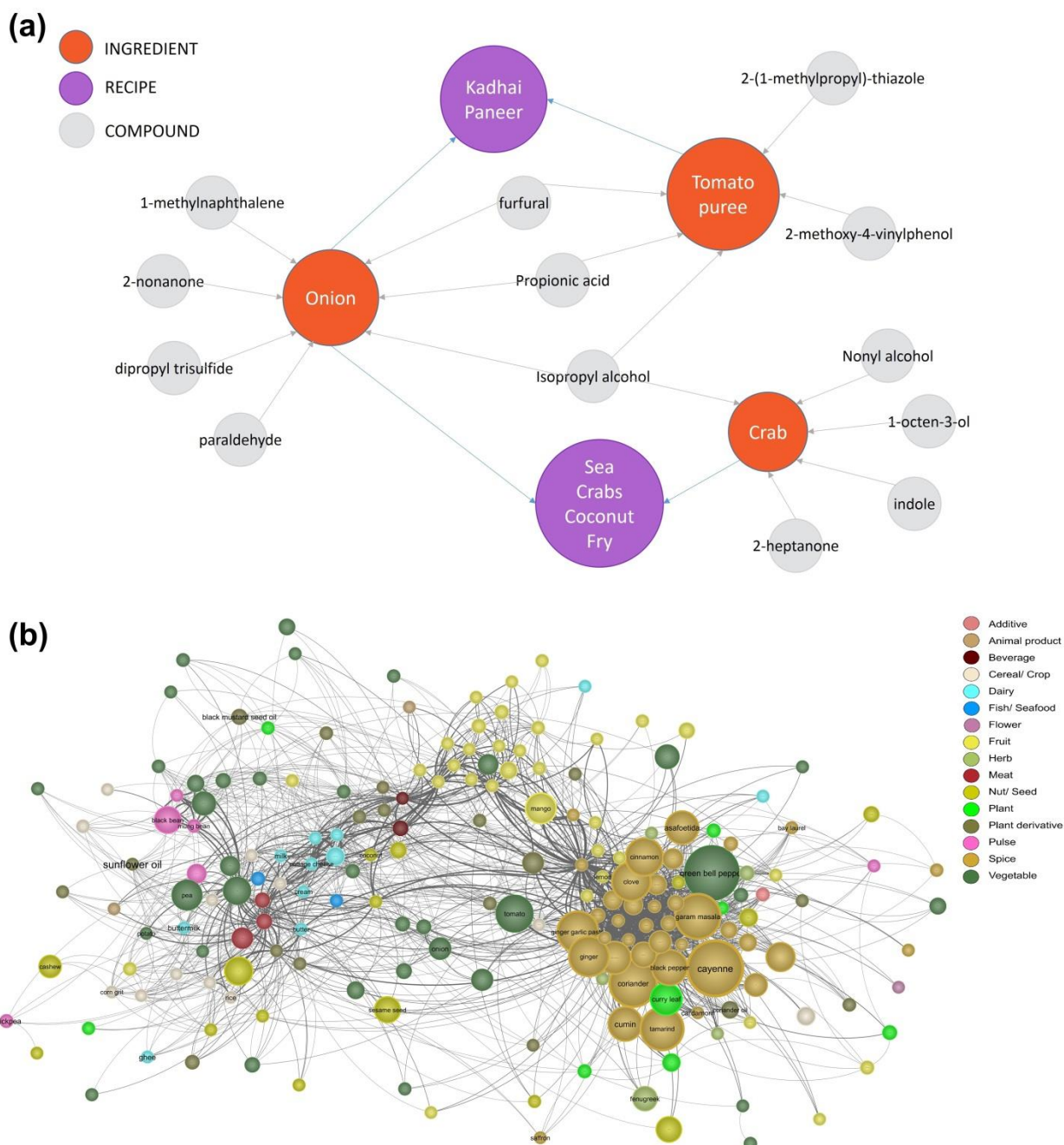
A.1 SUPPLEMENTARY FIGURES

Figure A.1.1: Construction of flavor graph. (A) Illustration for construction of flavor graph of a cuisine starting from its ingredients set and their flavor profiles. (B) The backbone extracted [Serrano, Boguñá, and

Vespignani 2009] flavor graph of Indian cuisine. Ingredients are denoted by nodes and the presence of shared flavor profile between any two ingredients is depicted as a link between them. The color of the node reflects the ingredient category and the thickness of edges is proportional to the extent of flavor profile sharing. Node size is scaled to the ingredient's contribution to negative food pairing of the cuisine
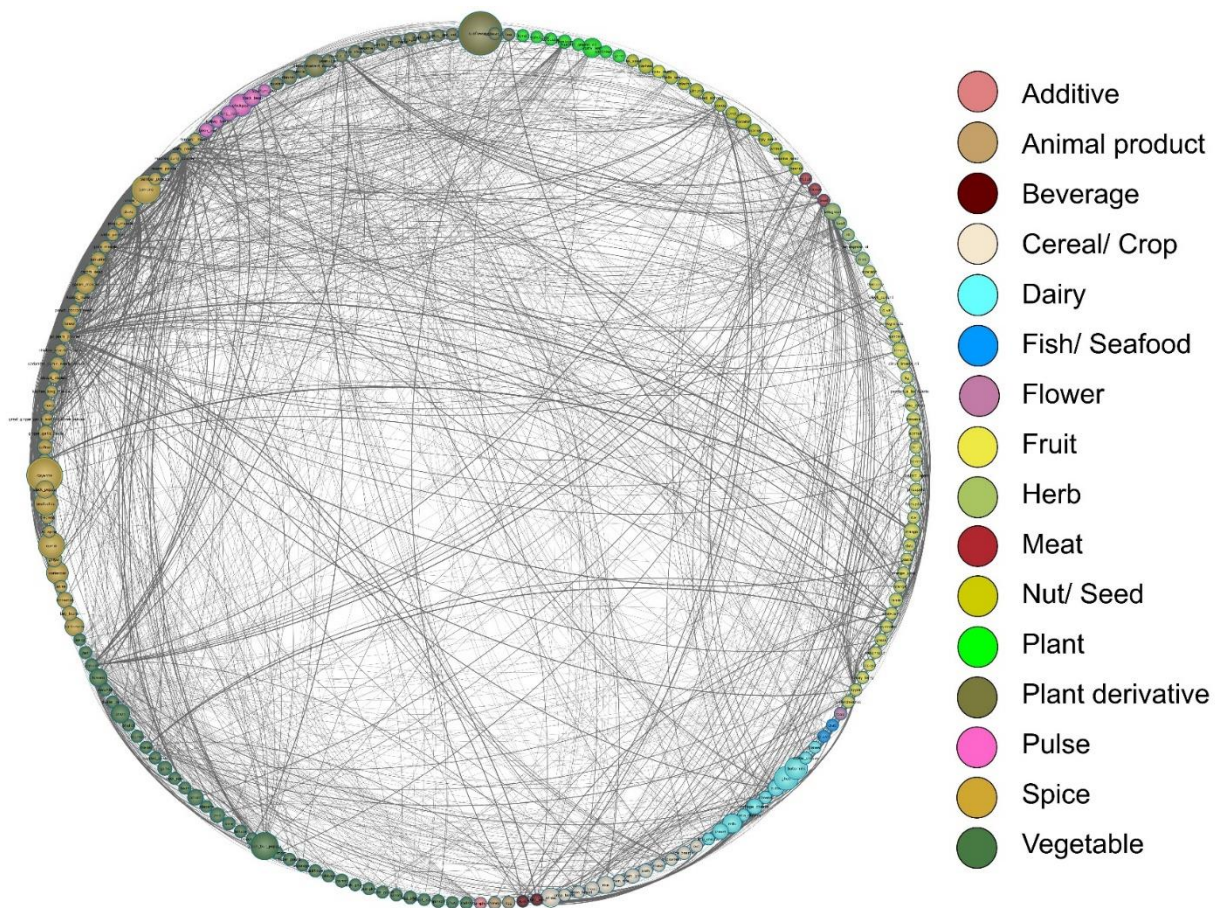

Figure A.1.2: The backbone of the flavor graph of Indian cuisine. Each of the 194 ingredients is depicted as a node and shared flavor compounds are shown as edges. The size of the node is scaled to the frequency of use of the ingredient, whereas the thickness of the edge is scaled to the number of shared flavor compounds
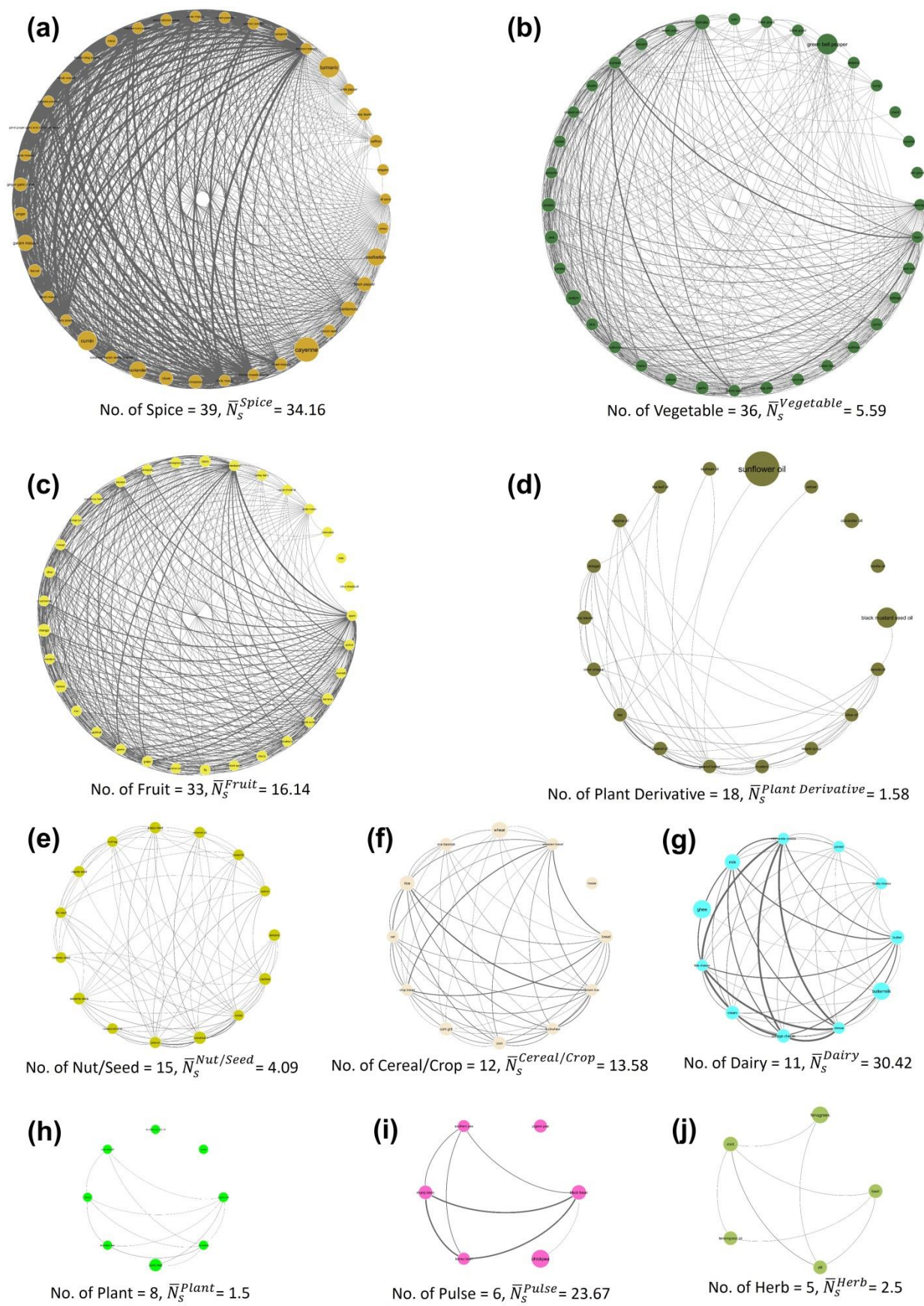
(a)

No. of Spice = 39, $\overline{N}_S^{Spice}$ = 34.16

(b)

No. of Vegetable = 36, $\overline{N}_S^{Vegetable}$ = 5.59

(c)

No. of Fruit = 33, $\overline{N}_S^{Fruit}$ = 16.14

(d)

No. of Plant Derivative = 18, $\overline{N}_S^{Plant\ Derivative}$ = 1.58

(e)

No. of Nut/Seed = 15, $\overline{N}_S^{Nut/Seed}$ = 4.09

(f)

No. of Cereal/Crop = 12, $\overline{N}_S^{Cereal/Crop}$ = 13.58

(g)

No. of Dairy = 11, $\overline{N}_S^{Dairy}$ = 30.42

(h)

No. of Plant = 8, $\overline{N}_S^{Plant}$ = 1.5

(i)

No. of Pulse = 6, $\overline{N}_S^{Pulse}$ = 23.67

(j)

No. of Herb = 5, $\overline{N}_S^{Herb}$ = 2.5

Figure A.1.3: Flavor sharing within the ingredient category. Intra-category flavor sharing pattern for 10 (of 15) major ingredient categories. The categories are color-coded as per the legends in Figure A.1.2B. (A) Spice, (B) Vegetables, (C) Fruit, (D) Plant derivative, (E) Nut/Seed, (F) Cereal/Crop, (G) Dairy, (H) Plant, (I) Pulse, (J) Herb
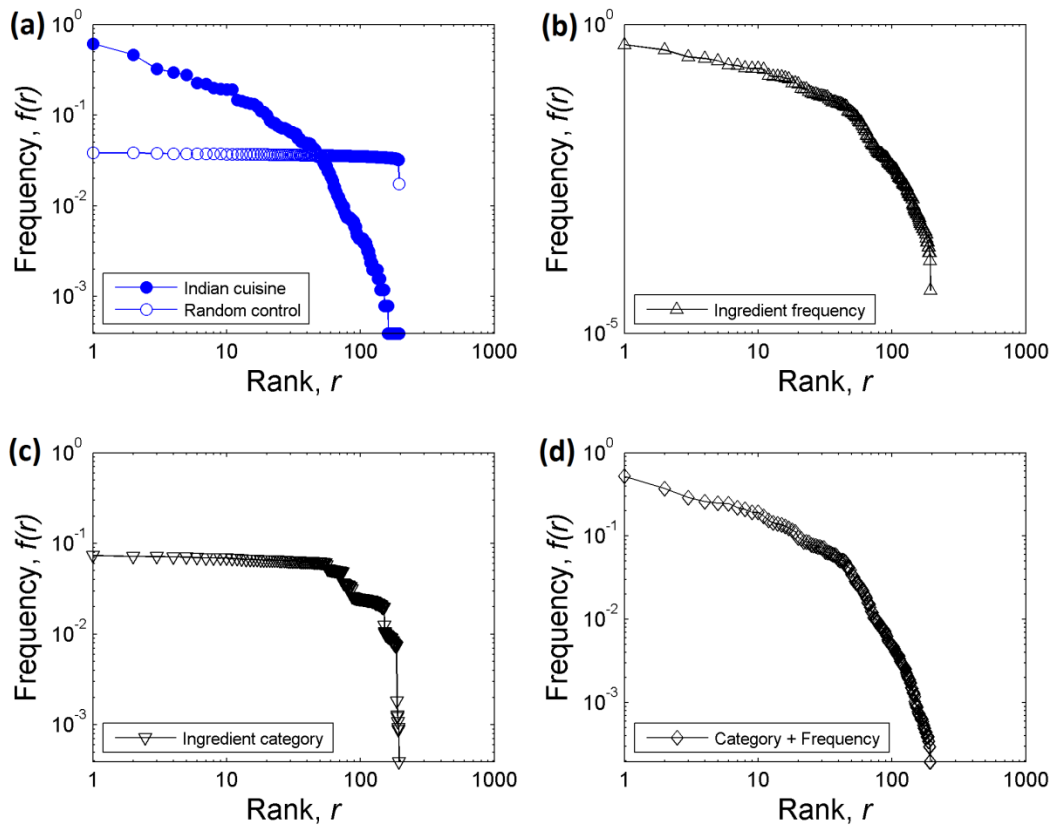
Figure A.1.4: Ingredient rank profiles of Indian cuisine and controls. (a) Random control when compared to Indian cuisine. (b) Control with ingredient frequency preserved. (c) Control that preserved only the ingredient category composition of a recipe. (d) Control in which, both, the frequency of use of ingredients as well as the category composition were preserved
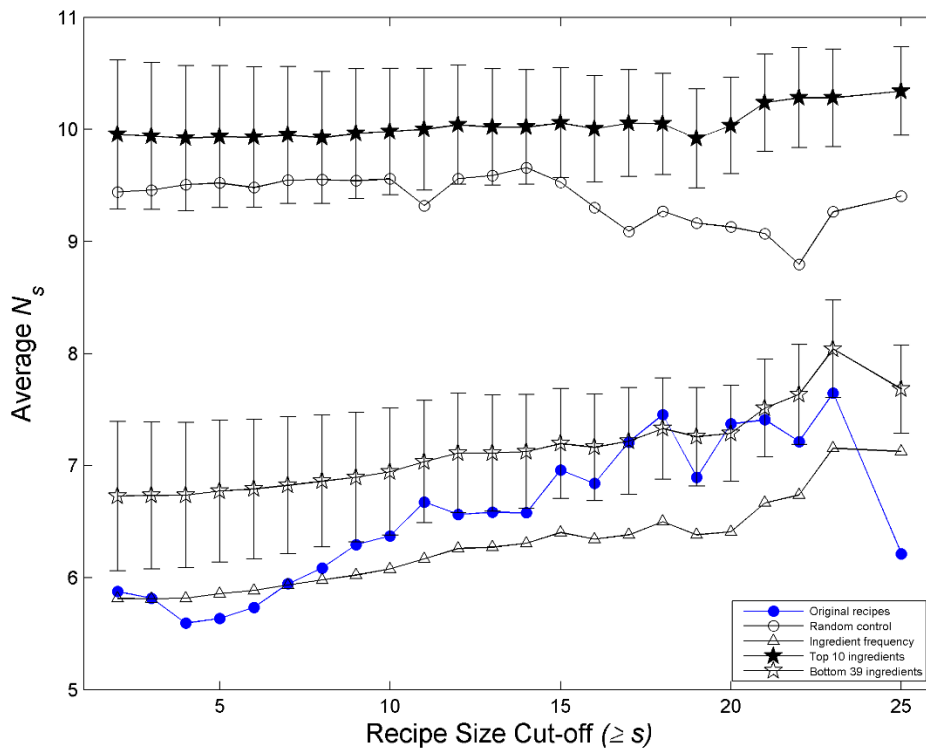

Figure A.1.5: Role of most frequently used ingredients in the negative food pairing pattern of Indian cuisine. Frequency preserved random control with top 10 ranked ingredients swapped randomly with low-ranked ingredients exhibited food pairing pattern similar to a randomized cuisine. On the other hand, when poorly

ranked ingredients (bottom 39 ingredients; equally ranked) were subjected to similar random swapping, the food pairing was less affected. This highlighted that high-ranked ingredients are critical in specifying the characteristic profile of Indian cuisine. The error bars indicate the standard deviation over ten experiments.

A.2 RESOURCES USED FOR COMPILATION OF FLAVOR MOLECULES

Fenaroli's Handbook of Flavor Ingredients [Burdock, 2010] (References therein), FooDB (http://foodb.ca), Flavornet [Arn and Acree, 1998], SuperSweet [Ahmed et al., 2011], BitterDB [Wiener et al., 2012], data from previously published resources such as Ahn et.al. [Ahn et al., 2011], Jain et.al.[Jain et al., 2015a], and other references [Ahn et al., 2011; Bekhechi et al., 2010; Braca, Siciliano, D'Arrigo, and PaolaGermanò, 2008; Burdock, 2010; Chatterjee, Sharma, Variyar, and Sharma, 2009; Chowdhury, Bhuiyan, and Yusuf, 2008; Freidig and Goldman, 2014; Gallardo-Escamilla, Kelly, and Delahunty, 2005; Huang et al., 2009; Huffman, Schadle, Villalon, and Burns, 1978; Jagella and Grosch, 1999; Jones and Greenshields, 1969; Juita, Dlugogorski, Kennedy, and Mackie, 2012; Kobaisy et al., 2001; Krist, Stuebiger, Unterweger, Bandion, and Buchbauer, 2005; Kumar et al., 2011; Lucas, 1999; MacLeod and De Troconis, 1983; Mahadkar, Valvi, and Jadhav, 2013; Martinez-Velazquez, R, Flores-Fernandez, and Lopez-Ramirez J Hernandez-Gutierrez R, 2011; Mayuoni-Kirshinbaum and Porat, 2014; Mukunzi et al., 2011; Nf and Velluz, 2000; Nickavara, Mojab, Javidnia, and Roodgar Amoli, 2003; Noleau, Richard, and Peyroux, 1991; Ogunbinu, Flamini, Cioni, Adebayo, and Ogunwande, 2009; Ogunwande et al., 2013; Pino, Escalona, Licea, Perez, and Aguero, 2002; Rajanikanth, Ravindranath, and Shankaranarayana, 1984; Sharma, Chatterjee, Kumar, Variyar, and Sharma, 2010; Taveira et al., 2009; Wong, Chong, and Chee, 1998; Yang, Shewfelt, Lee, and Kays, 2008; Zhao, Niu, Li, Dong, and Huang, 2009]

A.3 SUPPLEMENTARY DATA TABLES FOR INDIAN CUISINE

Table A.3.1: List of major ingredients not reported in other cuisines and are commonly used in Indian cuisine

S. No.	Ingredient name	Category	Frequency of occurrence
1	Ghee	Dairy	573
2	Asafoetida	Spice	561
3	Garam masala	Spice	372
4	Curry leaf	Spice	349
5	Ginger garlic paste	Spice	166
6	Carom seed	Spice	111
7	Pigeon pea	Pulse	90
8	Coriander cumin seeds powder	Spice	87
9	Chat masala	Spice	86
10	Poppy seed	nut/seed	83
11	Rice basmati	cereal/crop	69
12	Nigella seed	nut/seed	53
13	Eggplant	Vegetable	51
14	Spinach	Vegetable	41
15	Pomegranate	Fruit	38
16	Sambar powder	Spice	22
17	Bitter gourd	Vegetable	15
18	Bottle gourd	Vegetable	15
19	Chole masala	Spice	15
20	Colocasia	Plant	11
21	*Pandanus fasicularis*	Fruit	11
22	Rasam powder	Spice	11
23	White pepper	Spice	11

Table A.3.2: List of top 15 ingredients contributing to positive and negative food pairing in Indian cuisine

Ingredients contributing to positive food pairing	χ value	Frequency of occurrence	Ingredients contributing to negative food pairing	χ value	Frequency of occurrence
Milk	0.336059	341	Cayenne	-0.13858	1179
Butter	0.314603	188	Green bell pepper	-0.13416	756
Bread	0.113016	106	Coriander	-0.07823	486
Rice	0.087081	256	Garam masala	-0.06694	372
Cottage cheese	0.073573	172	Tamarind	-0.05921	126
Corn	0.071018	84	Ginger garlic paste	-0.04756	166
Cheese	0.068223	21	Ginger	-0.04743	158
Lemon	0.046303	165	Clove	-0.04557	208
Grape	0.044927	18	Cinnamon	-0.04436	182
Cream	0.042721	179	Tomato	-0.04381	281
Honey	0.037645	28	Black pepper	-0.04037	275
Olive	0.037088	48	Cumin	-0.03335	705
Cocoa	0.036144	10	Asafoetida	-0.03201	561
Coconut	0.035244	158	Coriander cumin seeds powder	-0.03032	87
Strawberry	0.030408	10	Curry leaf	-0.02967	349

Table A.3.3: List of derived ingredients which are combinations of spices

S. No.	Ingredient name	Constituent spices	Frequency of occurrence
1	Garam masala	Black pepper, mace, cinnamon, clove, cardamom, nutmeg	372
2	Ginger garlic paste	Ginger, garlic	166
3	Coriander cumin seeds powder	Coriander, cumin	87
4	Chaat masala	Asafoetida, mango, black salt, cayenne, garlic, ginger, roasted sesame seed, black mustard seed oil, turmeric, coriander, bay laurel, star anise, fennel	86
5	Sambar powder	Pigeon pea, coriander, chickpea, cumin, black pepper, cayenne, ginger, fenugreek, turmeric	22
6	Chole masala	Cayenne, garlic, ginger, roasted sesame seed, black mustard seed oil, turmeric, coriander bay laurel, star anise, fennel	15
7	Rasam powder	Cayenne, pigeon pea, cumin, coriander, black pepper, curry leaf	11
8	Tandoori masala	Garlic, ginger, clove, nutmeg, mace, cumin, coriander, fenugreek, cinnamon, cardamom, black pepper	8
9	Curry powder	Cardamom, cayenne, cinnamon, clove, coriander, cumin, fennel fenugreek, mace, nutmeg, black pepper, poppy seed, roasted sesame seed, saffron, tamarind, turmeric	5
10	Kitchen king masala	Bay laurel, ginger, cinnamon, clove, black pepper, coriander, fennel, cayenne	5

11	Panch phoron seeds	Fenugreek, nigella seed, cumin, Black mustard seed oil, fennel	4
12	Chicken masala powder	Bay laurel, ginger, cinnamon clove, black pepper, coriander, fennel, cayenne	2
13	Goda masala	Cardamom, cinnamon, clove, Bay laurel, roasted sesame seed, Coriander, roasted coconut, Cassia, white pepper, Black pepper	2
14	Madras curry powder	Cardamom, cayenne, cinnamon, clove, coriander, cumin, fennel, fenugreek, mace, nutmeg, black pepper, poppy seed, saffron, tamarind, turmeric	1
15	Jal jeera masala	Black salt, mango, cumin, citric acid, mint, black pepper, ginger, asafetida	1
16	Kebab masala	Bay laurel, ginger, cinnamon, clove, black pepper, coriander, fennel, cayenne	1
17	Grind ginger garlic and coriander leaves	Ginger, garlic, coriander	1
18	Pulao masala	Black pepper, white pepper, clove, cumin, cinnamon, cardamom, coriander	1
19	Dabeli masala	Cayenne, coriander, cinnamon, clove, cumin	1

A.4 SUPPLEMENTARY DATA TABLES FOR INDIAN REGIONAL CUISINE(S)

Table A.4.1: Number of ingredients in each category for all regional cuisines

Ingredient Category	Bengali	Gujarati	Jain	Maharashtrian	Mughlai	Punjabi	Rajasthani	South Indian
Spice	25	23	26	25	24	33	21	25
Vegetable	14	23	29	14	15	29	16	23
Fruit	13	19	25	9	16	22	5	14
Plant derivative	8	7	11	7	8	13	4	6
Nut/seed	12	12	12	11	11	13	8	10
Cereal/Crop	6	10	11	6	9	12	7	9
Dairy	7	6	8	6	7	10	5	7
Plant	2	3	3	3	4	5	4	5
Pulse	4	6	5	4	5	6	5	6
Herb	2	2	5	3	3	4	2	3
Meat	3	0	0	2	0	1	0	0
Beverage	1	0	1	1	0	1	0	0
Fish/Seafood	2	0	0	0	0	0	0	2
Animal product	2	0	1	1	2	2	0	2
Flower	1	1	1	1	1	1	1	1
Additive	0	0	0	0	0	0	0	1

Table A.4.2: Exponents (α) for regional cuisines and their random controls

Cuisine	α Values				
	Original	R0	R1	R2	R3
Bengali	0.255525	0.181436	0.255149	0.190506	0.26209
Gujarati	0.405862	0.187475	0.365109	0.207978	0.37633

Jain	0.226656	0.155991	0.235283	0.138507	0.228731
Maharashtrian	0.282265	0.158809	0.259422	0.141178	0.269226
Mughlai	0.184891	0.173672	0.202563	0.143178	0.194965
Punjabi	0.207118	0.150068	0.207771	0.120212	0.215736
Rajasthani	0.315478	0.223507	0.35912	0.209513	0.351726
South Indian	0.300892	0.189509	0.280907	0.213137	0.290387

Table A.4.3: Power law exponents (γ) of all regional cuisines

Cuisine	γ Values
Bengali	1.71906
Gujarati	2.11136
Jain	1.77156
Maharashtrian	1.6974
Mughlai	1.47354
Punjabi	1.55844
Rajasthani	2.62489
South Indian	1.948

Table A.4.4: Details of top 10 ingredients contributing to positive and negative food pairing in each of the regional cuisines

Bengali					
Ingredients contributing to negative food pairing	χ value	Frequency of occurrence	Ingredients contributing to positive food pairing	χ value	Frequency of occurrence
coriander	-0.23888	40	Milk	0.8456	31
ginger garlic paste	-0.2113	16	cottage cheese	0.38798	11
garam masala	-0.1976	14	Orange	0.21877	4
Mango	-0.1948	13	Buttermilk	0.1723	25
cayenne	-0.12799	65	Coconut	0.1309	12
Tomato	-0.11172	14	Rose	0.12196	5
tamarind	-0.10923	9	Cocoa	0.08273	5
green bell pepper	-0.09923	26	Strawberry	0.05565	2
Cumin	-0.06678	36	Cream	0.05392	5
mung bean	-0.0665	4	Saffron	0.05345	14
Gujarati					
Ingredients contributing to negative food pairing	χ value	Frequency of occurrence	Ingredients contributing to positive food pairing	χ value	Frequency of occurrence
green bell pepper	-0.28264	169	Cardamom	0.17264	43
cayenne	-0.18454	145	Milk	0.15930	34
mung bean	-0.09632	37	Mango	0.15741	20
coriander	-0.05721	45	Lemon	0.12145	31
garam masala	-0.05433	26	Strawberry	0.07504	2
black pepper	-0.05096	33	chaat masala	0.06809	4
asafoetida	-0.04571	169	Apple	0.06072	2

Ingredients contributing to negative food pairing	χ value	Frequency of occurrence	Ingredients contributing to positive food pairing	χ value	Frequency of occurrence
coriander cumin seeds powder	-0.04331	26	Mint	0.06037	11
sesame seed	-0.04201	62	Apricot	0.05953	1
ginger garlic paste	-0.03269	7	cottage cheese	0.0576	4

Jain

Ingredients contributing to negative food pairing	χ value	Frequency of occurrence	Ingredients contributing to positive food pairing	χ value	Frequency of occurrence
Cayenne	-0.18227	152	Butter	1.2301	68
garam masala	-0.14025	28	Milk	0.8578	62
Mango	-0.11309	24	Bread	0.26934	25
black bean	-0.0817	33	Corn	0.26079	29
Coriander	-0.06735	47	Cocoa	0.14723	3
Tamarind	-0.06731	17	Cream	0.11812	37
black pepper	-0.06074	55	peanut butter	0.09937	4
Ginger	-0.05991	17	Grape	0.09096	4
green bell pepper	-0.05788	112	Cheese	0.08817	11
chaat masala	-0.05534	14	Strawberry	0.08282	4

Maharashtrian

Ingredients contributing to negative food pairing	χ value	Frequency of occurrence	Ingredients contributing to positive food pairing	χ value	Frequency of occurrence
Cayenne	-0.20477	71	Strawberry	0.18781	1
green bell pepper	-0.16417	27	Apricot	0.17944	1
Cardamom	-0.12939	28	Milk	0.14823	11
Peanut	-0.11493	10	Butter	0.09373	3
Tamarind	-0.11186	12	Cheese	0.08047	1
Tomato	-0.10615	8	Coconut	0.05305	22
black bean	-0.09883	6	sesame seed	0.04631	6
black pepper	-0.09592	16	cream	0.04279	2
Cinnamon	-0.0875	21	cocoa	0.0426	1
Coriander	-0.0807	30	rice	0.03168	11

Mughlai

Ingredients contributing to negative food pairing	χ value	Frequency of occurrence	Ingredients contributing to positive food pairing	χ value	Frequency of occurrence
Ginger	-0.21549	20	milk	0.97534	71
garam masala	-0.20182	38	rice	0.47004	9
Clove	-0.16439	42	bread	0.16394	12
Cinnamon	-0.14922	33	grape	0.16237	3
Tomato	-0.12297	21	mango	0.15239	11
green bell pepper	-0.09791	33	lemon	0.14948	8
ginger garlic paste	-0.09628	22	chaat masala	0.14043	13
Cayenne	-0.08124	70	honey	0.12692	3
Onion	-0.06795	29	cream	0.11308	38
Coriander	-0.06755	38	cardamom	0.09142	72

Punjabi

Ingredients contributing to negative food pairing	χ value	Frequency of occurrence	Ingredients contributing to positive food pairing	χ value	Frequency of occurrence
garam masala	-0.18885	251	milk	0.16853	137
green bell pepper	-0.14559	301	bread	0.12553	60
Cayenne	-0.12081	496	butter	0.10939	87
Tomato	-0.10305	137	cheese	0.09834	7
Mango	-0.10142	120	corn	0.05485	34
ginger garlic paste	-0.09549	110	lemon	0.04881	80
Ginger	-0.0862	82	cottage cheese	0.03852	128
coriander	-0.08364	243	grape	0.03832	4
cinnamon	-0.06514	84	honey	0.03592	11
Clove	-0.05827	86	olive	0.03389	16

Rajasthani

Ingredients contributing to negative food pairing	χ value	Frequency of occurrence	Ingredients contributing to positive food pairing	χ value	Frequency of occurrence
garam masala	-0.13296	15	ginger	0.21724	3
coriander	-0.08503	35	mango	0.15534	21
Clove	-0.07637	16	milk	0.14771	21
Cumin	-0.06656	55	corn	0.09159	2
cinnamon	-0.05187	9	tamarind	0.07866	4
coriander cumin seeds powder	-0.04701	4	cardamom	0.04301	31
Potato	-0.03463	3	butter	0.03701	2
asafetida	-0.03403	40	green bell pepper	0.03228	33
black pepper	-0.03086	9	lemon	0.02875	3
mung bean	-0.02856	12	bread	0.02778	2

South Indian

Ingredients contributing to negative food pairing	χ value	Frequency of occurrence	Ingredients contributing to positive food pairing	χ value	Frequency of occurrence
tamarind	-0.13496	87	rice	0.43234	119
Tomato	-0.11615	51	garam masala	0.25433	24
green bell pepper	-0.10884	144	butter	0.19496	16
cayenne	-0.09523	238	black bean	0.18541	150
coriander	-0.06546	73	coconut	0.17793	68
curry leaf	-0.05149	196	mung bean	0.13343	34
Peanut	-0.05013	16	milk	0.13271	26
Ginger	-0.04182	24	cardamom	0.06391	46
Lemon	-0.03325	20	soybean	0.04416	8
Cumin	-0.03094	135	onion	0.0303	72

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