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Original article

Characteristics and trends in global tea research: a Science Citation Index Expanded-based analysis

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Summary A bibliometric approach to assess trends in global tea research using literature in the Science Citation Index Expanded database from 1991 to 2014 has been conducted. Articles were analysed by scientific output and research performances of countries and institutions. The distribution of keywords in the articles' titles, author-supplied keywords and *KeyWords Plus* as well as citation and publication trends of tea-related articles was used to evaluate the research trends. The research output devoted to tea science increased greatly after the year 2002 indicating a paradigm shift that demonstrated that researchers became increasingly keen on biochemical relevance of active compounds in tea in mitigating emergent health challenges over classical tea research.

Keywords bibliometric studies, literature review, research collaborations, research institutions, tea research.

Introduction

Tea is the most popular beverage taken by all kinds of people world over. More than two-thirds of people in the world regularly consume tea as their morning drink (Mondal *et al*., 2004). Tea is, therefore, one of the commodities that control global markets and is relevant to the economies of many countries of the world (Hicks, 2009). The main tea-producing countries include China (1047.4kt), India (945.3kt), Kenya (313kt), Sri Lanka (312.0kt) and Turkey (200.1kt) (FAO, 2008), and the common tea types produced for international markets include green, black, oolong, white, yellow and compressed tea. However, the global tea market continues to expand by day (Hicks, 2009). Consequently, tea research has assumed multidisciplinary dimensions traversing such fields as environmental science, agriculture, technology, industry, biotechnology and health (Chen, 2007).

As expected, there has been an upsurge in tea research related to the association of consumption of tea with a growing list of beneficial health effects in recent past (Cabrera *et al*., 2015). Thus, in order to gain insight into factors that control this resurgence in order to understand current trends in differential involvement of scientists in tea research, we explored a bibliometric approach to assess tea literature in the online version of Science Citation Index Expanded (SCI-EXPANDED), the Thomson Reuters Web of Science. The analyses were aimed to unravel patterns that could help to consolidate research data across multidisciplinary aspects, present researchers with a broader view of the existing trends, and provide insight into the direction of science in global tea research, which would help to devise approaches for improved research performance (Chuang *et al*., 2012).

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Materials and methods

The data were based on online version of the SCI-EXPANDED in the Thomson Reuters Web of Science (updated on 12 September 2015). 'Tea' was searched in terms of topic (including the four parts: title, abstract, authors' keywords and *KeyWords Plus*) within the publication years from 1991 to 2014. In total, 31 374 documents met the selection criteria. Because the original article is the main peer-reviewed document type that proposes novel concepts and presents substantive research findings, article was the only document type considered.

Another filter, the 'front page' (Fu *et al*., 2012), meant that only articles with search words in their 'front page' including article title, abstract and author keywords were included. This yielded 31 374 articles,

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which were regarded as the tea publications in the 24-year period. The full record of Web of Science Core Collection and the number of citations in each year for each article was downloaded into *Microsoft Excel 2010* and additional coding manually performed. The journal impact factors (IF_{2014}) were taken from the *Journal Citation Reports* (*JCR*) published in 2014.

In the SCI-EXPANDED database, the author to whom all correspondence should be addressed was designated the 'reprint' author but the term 'corresponding author' was employed in this study instead. In a single-author article where authorship was unspecified, the single author was designated both the first author and the corresponding author. Similarly, for a single-institution article, the institution was classified as the first author's institution and the corresponding author's institution. Articles originating from England, Scotland, Northern Ireland and Wales were reclassified as being from the United Kingdom (UK). Articles from Hong Kong and Macao were included under the heading of China (Fu and Ho, 2012). Articles from Zaire were reclassified as being from the Democratic Republic of the Congo (Dem Rep Congo) (Pouris & Ho, 2014). Articles from Czechoslovakia were checked and reclassified as being from Slovakia and Czech Republic, respectively (Lin & Ho, 2015). Articles from Yugoslavia were checked and reclassified as being from Serbia, Serbia Montenegro and Croatia, respectively. Articles from USSR were checked and reclassified as being from Russia, Ukraine and Belorussia, respectively. Acad Sci USSR and USSR Acad Sci were also reclassified as being the Russian Academy of Sciences (Russian Acad Sci).

Contributions of different institutions and countries were estimated by the affiliation of at least one author to the publications. Collaboration types were determined by the addresses of the authors, where the term 'single country article' was assigned if the researchers' addresses were from the same country. The term 'internationally collaborative article' was designated to articles that were co-authored by researchers from multiple countries. The term 'single institution article' was assigned if all the researchers' addresses were from the same institution and the term 'inter-institutionally collaborative article' was assigned if authors were from different institutions.

Results and discussion

Analysis of citation trends

Analysis of the relationship between citations per publication up to the year 2014 ($CPP = TC_{2014}/TP$) and the number of years since the article's publication for the 31 374 tea research articles (Ho & Kahn, 2014) showed that *CPP* increased rapidly during the first 2 years since publication to a peak *CPP* of 2.9 in the 3rd year, and decreased in the subsequent years. Similar studies have reported peak *CPP* in the 2nd year (Chiu & Ho, 2005), 3rd year (Adams, 2005), 4th year (Ayres & Vars, 2000) and in the 5th year (Li & Ho, 2008), respectively.

The rapid increase in *CPP* and the immediate 'cool off' after just 2 years of article publication observed in this study is uncharacteristic of a matured research field as would be expected of classical tea research. It indicated that increasingly more papers were being generated, which provided readers with variety of options to cite from. The field of tea science was, therefore, experiencing rapid expansion generation huge volumes of data around emergent research themes.

Publication outputs

The annual publication output and mean *CPP* for the years 1991–2014 are displayed in the figure. The publication output increased from just 425 articles in 1991 to 1063 articles between 1998 and 2002. The initially sigmoid shape of the graph of publication output vs. time indicated that tea research reached pseudo-maturity during between the years 1991 and 2002 before a rejuvenated interest in tea research with steady increase in research output from just 1094 articles in 2003 to 2491 articles in 2014. The rate of growth in tea research during this period was as strong as that observed in hotspot research areas such as tropical medicine (Falagas *et al*., 2006), meteorology (Li *et al*., 2009) and drinking water (Fu *et al*., 2013).

The highest *CPP* for the articles occurred in 1993. This was attributed to highly cited tea research article by Hertog *et al*. (1993) published in this field during this year. In the same way, the second highest *CPP* in 1992 was ascribed to another high-impact article by Graham (1992).

The time dependence of citation trends of research articles provides information that is useful for tracking the impact of the articles. The citation trends of the highly cited article by Hertog *et al*. (1993) reveal that only 265 of the 2664 citations for this article occurred within 1993–1997 period and that the larger proportion (90% of the citations) was accrued between 1998 and 2014. Similar trends were observed for the other classic articles (Scalbert & Williamson, 2000). The periods of highest visibility of these classic articles coincided with the period of revitalisation in tea science (Fig. 1).

Language of publication

The language of publication is one of the indicators that provide information about players in a research

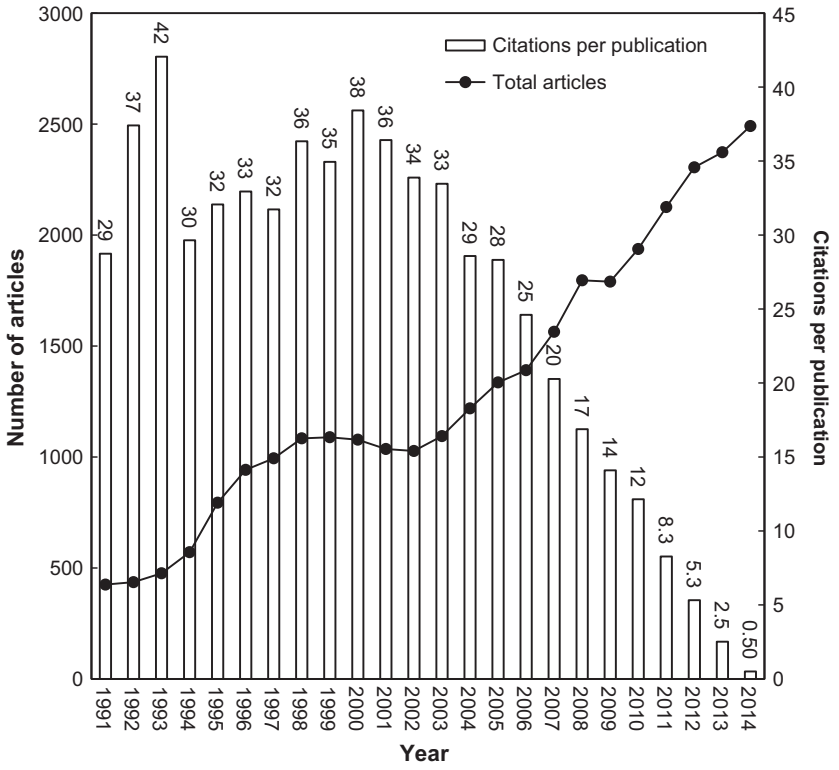

Figure 1 Number of articles and citations per publication by year.

process. At least 22 languages were found to have been used in the publication of the 31 374 articles in tea science during the 1991–2014 period. In total, 98% of all the articles were published in English, followed by the proportion of articles published in Japanese (1.1%), Chinese (0.85%), German (0.49%), Portuguese (0.30%), French (0.25%), Spanish (0.25%), Russian (0.18%), Polish (0.13%), Korean (0.061%), Turkish (0.051%), Italian (0.029%), Rumanian (0.019%) and Czech (0.016). Thirty-six percentage of the 1169 non-English articles had no citations ($TC_{2014} = 0$). Furthermore, 18% of these articles had $TC_{2014} = 1$, and 13% had $TC_{2014} = 2$. Conversely, 13%, 7.5% and 5.9% of the English articles had $TC_{2014} = 0$, $TC_{2014} = 1$ and $TC_{2014} = 2$, respectively. In all, 4273 articles had $TC_{2014} = 0$.

Characteristics of tea research articles between 1991 and 2014

The increase in the annual output of articles in tea science (TP) paralleled the rise in the number of participating authors. It was unusual, however, that as the number of authors per article (AU/TP) and the number of bibliographic citations per article (NR/TP) increased, the number of pages per articles (PG/TP) decreased from 8.9 to 7.7 between 1991 and 2009 before eventual increase to 8.9 between 2010 and 2014. This could be attributed to the changing publication policies of the journals at the time. The *Journal of Agriculture and Food Chemistry* ($TP = 984$) and *Food Chemistry* ($TP = 662$), for instance, insisted on concise research papers of 6–8 pages only.

Performance of countries and research institutions

By analysing performances of countries, the mainstream participants and collaborators in research can be obtained. A total of 157 countries participated in tea researches during the current period of study. The largest proportion of articles originated from Asia (15 766) followed by those from Europe (10 568), North America (7650), South America (1551), Africa (1083) and Oceania (893).

Most productive countries

The research characteristics of the top most productive countries in tea research during this period were analysed and ranked by total output of articles with five indicators including independent articles, internationally collaborative articles, first-author articles, corresponding-author articles and single-author articles (Table 1). International collaborations accounted for 17% of all articles compared to 83% of the articles emanating from single-country research. At least

Table 1 Top ten countries in tea research output during the period 1991–2014

Country	TP	*TPR* (%)	*IPR* (%)	*CPR* (%)	*FPR* (%)	*RPR* (%)	*SPR* (%)
USA	6727	1 (22)	1 (18)	1 (38)	1 (18)	1 (18)	1 (27)
Japan	4355	2 (14)	2 (14)	4 (14)	2 (13)	2 (13)	2 (10)
China	4332	3 (14)	3 (13)	2 (18)	3 (12)	3 (13)	7 (3.4)
India	1971	4 (6.3)	4 (6.6)	13 (5.0)	4 (5.9)	4 (5.9)	6 (3.7)
UK	1765	5 (5.6)	6 (3.7)	3 (15)	5 (4.3)	5 (4.2)	3 (7.4)
Germany	1519	6 (4.9)	7 (3.6)	5 (11)	7 (3.8)	7 (3.9)	4 (6.5)
South Korea	1457	7 (4.7)	5 (4.1)	7 (7.7)	6 (4.1)	6 (4.2)	12 (2.1)
Italy	1038	8 (3.3)	10 (2.6)	8 (7.2)	9 (2.6)	9 (2.7)	20 (1.1)
Brazil	923	9 (3.0)	8 (2.9)	16 (3.1)	8 (2.7)	8 (2.7)	19 (1.2)
Canada	923	9 (3.0)	13 (2.2)	9 (7.0)	12 (2.3)	13 (2.2)	10 (2.5)

TP: total articles; TPR (%): rank and percentage of total articles; IPR (%): rank and percentage of independent articles; CPR (%): rank and percentage of internationally collaborative articles; FPR (%): rank and percentage of first-author articles; RPR (%): rank and percentage of the corresponding-authored articles; SPR (%): rank and percentage of single-author articles.

twenty countries participated in authorship of at least 325 tea research articles during this period. The USA (22% of all articles) was the most productive country, followed by Japan (14%), China (14%), India (6.3%) and the UK (5.6%). The top twenty countries in tea research constituted mainly of countries from Western Europe (10) and the Far East (5). South Africa (308 articles) was the most productive African country, and it ranked 21st in the world, followed by Egypt (243 articles, 23rd) and Kenya (130, 40th), respectively.

Thus, the tea-producing countries from the Far East were responsible for the highest proportion of tea research (15 766 articles), followed by tea-consuming Western Europe (10 568 articles) and North American (7650 articles) countries (FAO, 2008), respectively. There were no African countries among the twenty most productive countries in tea research. This could be because most of African tea is produced for export markets and only a small proportion is consumed locally.

The USA and Japan, the top two most productive countries in regard to total number of articles (*TP*), were also the top countries with respect to independent articles (*IP*), first-author articles (*FP*), corresponding-author articles (*RP*) and single-author articles (*SP*). Furthermore, the top five countries by *TPR* were also the top countries by *IPR*, *FPR* and *RPR* showing that the country's rank and percentage research output in tea science controlled its share of *IP*, *FP* and *RP*. Nevertheless, the country's research output in collaborative articles (*CPR* %), and single-author articles (*SPR* %), was not correlated with its total research output. This is because international research collaborations tend to 'equalise' countries' research capacities. The variance between the proportion of single-author articles and the country's total research output indicated that the amount of single-author research varied from country to country depending on national research policies.

The USA and Japan were the two most productive countries in tea research throughout the 1990s but, from about 1995 onwards, their annual publication output stagnated at about 300 and 200 articles, respectively. On the other hand, the research output from the Far East like China, India and South Korea sky-rocketed during this period showing that these countries spearheaded the observed renaissance that characterised tea research after the year 2002.

Table 2 The top ten most productive institutions

Institution	TP	*TPR* (%)	*IPR* (%)	*ICPR* (%)	*NCPR* (%)	*FPR* (%)	*RPR* (%)	*SPR* (%)	*IP* (%)	*ICP* (%)	*NCP* (%)
Chinese Academy of Sciences, China	443	1 (1.4)	2 (0.82)	1 (2.0)	1 (1.9)	1 (1.0)	1 (1.0)	N/A	123 (28)	104 (23)	216 (49)
Zhejiang University, China	370	2 (1.2)	1 (0.91)	2 (1.6)	3 (1.3)	2 (1.0)	2 (1.0)	77 (0.17)	137 (37)	85 (23)	148 (40)
University of Shizuoka, Japan	278	3 (0.89)	7 (0.50)	131 (0.31)	2 (1.7)	3 (0.65)	3 (0.64)	N/A	75 (27)	16 (5.8)	187 (67)
Rutgers State University, USA	271	4 (0.87)	3 (0.73)	4 (1.5)	10 (0.78)	4 (0.60)	4 (0.59)	12 (0.43)	110 (41)	75 (28)	86 (32)
Kyushu University, Japan	224	5 (0.72)	10 (0.46)	91 (0.39)	4 (1.2)	5 (0.47)	5 (0.46)	77 (0.17)	69 (31)	20 (8.9)	135 (60)
Kyoto University, Japan	220	6 (0.70)	4 (0.55)	13 (0.93)	9 (0.80)	6 (0.45)	6 (0.44)	31 (0.26)	83 (38)	48 (22)	89 (40)
Harvard University, USA	210	7 (0.67)	76 (0.17)	3 (1.6)	5 (0.91)	23 (0.28)	28 (0.24)	4 (0.60)	25 (12)	84 (40)	101 (48)
National Taiwan University, Taiwan	192	8 (0.61)	13 (0.37)	23 (0.76)	6 (0.88)	7 (0.42)	7 (0.41)	77 (0.17)	56 (29)	39 (20)	97 (51)
Seoul National University, South Korea	168	9 (0.54)	43 (0.21)	16 (0.89)	7 (0.82)	21 (0.29)	16 (0.29)	77 (0.17)	31 (18)	46 (27)	91 (54)
USDA ARS, USA	160	10 (0.51)	6 (0.51)	50 (0.50)	20 (0.51)	9 (0.36)	9 (0.36)	1 (1.1)	77 (48)	26 (16)	57 (36)

TP: total number of articles; TPR (%): rank and percentage of total articles; IPR (%): rank and percentage of single-institution articles; ICPR (%): rank and percentage of interinstitutionally collaborative articles; NCPR (%): rank and percentage of nationally collaborative articles; FPR (%): rank and percentage of first-author articles; RPR (%): rank and percentage of the corresponding-authored articles; SP (%): rank and percentage of single-author articles; IP (%): the number of single-institution articles and percentage of single-institution articles in total articles of each institution; ICP (%): the number of internationally collaborative articles and percentage of internationally collaborative articles in total articles of each institution; NCP (%): the number of nationally collaborative articles and percentage of nationally collaborative articles in total articles of each institution; N/A: not available.

Table 3 List of the top 20 author-supplied keywords

Author keywords	TP	91-14 *R* (%)	91-96 *R* (%)	97-02 *R* (%)	03-08 *R* (%)	09-14 *R* (%)
Tea	1599	1 (6.8)	1 (6.7)	1 (8.2)	1 (7.4)	2 (5.9)
Green tea	1319	2 (5.6)	11 (1.5)	2 (4.5)	2 (6.6)	1 (6.1)
Polyphenols	690	3 (2.9)	58 (0.48)	5 (2.3)	3 (3.4)	3 (3.3)
Antioxidant	627	4 (2.7)	16 (1.1)	8 (2.1)	8 (2.7)	4 (3.1)
Catechins	612	5 (2.6)	77 (0.38)	3 (3.2)	4 (3.1)	9 (2.5)
Caffeine	570	6 (2.4)	3 (2.5)	4 (2.5)	9 (2.5)	10 (2.3)
EGCG	554	7 (2.4)	122 (0.27)	18 (1.1)	4 (3.1)	7 (2.8)
Camellia sinensis	543	8 (2.3)	8 (1.6)	10 (1.8)	11 (2.4)	8 (2.6)
Catechin	541	9 (2.3)	13 (1.2)	9 (2.0)	6 (2.8)	11 (2.3)
Flavonoids	515	10 (2.2)	45 (0.59)	6 (2.3)	9 (2.5)	13 (2.2)
Apoptosis	491	11 (2.1)	N/A	13 (1.5)	7 (2.8)	12 (2.3)
Antioxidant activity	474	12 (2.0)	97 (0.32)	36 (0.68)	14 (1.9)	5 (2.9)
Oxidative stress	474	12 (2.0)	66 (0.43)	25 (0.89)	16 (1.8)	6 (2.9)
Antioxidants	439	14 (1.9)	38 (0.65)	7 (2.2)	12 (2.1)	14 (1.8)
Black tea	391	15 (1.7)	8 (1.6)	11 (1.7)	15 (1.8)	16 (1.5)
Epigallocatechin Gallate	346	16 (1.5)	66 (0.43)	23 (1.0)	13 (1.9)	15 (1.6)
Coffee	345	17 (1.5)	7 (1.7)	15 (1.5)	18 (1.4)	17 (1.5)
Polyphenol	290	18 (1.2)	38 (0.65)	25 (0.89)	17 (1.5)	19 (1.3)
HPLC	257	19 (1.1)	28 (0.81)	21 (1.1)	22 (1.1)	21 (1.1)
Nitric oxide	246	20 (1.0)	23 (0.86)	12 (1.7)	20 (1.2)	29 (0.72)

TP: total articles; R: rank; N/A: not available.

Most productive institutions

Of the 31 262 articles with author addresses in SCI-EXPANDED, 15 016 were single-institution articles. At least ten research institutions participated in authorship of no less than 160 articles in tea research between 1991 and 2014. The ten most productive institutions were mainly from USA (3), Japan (3) and China (2), and both Taiwan and South Korea were represented by one institution (Table 2). Notably, among all institutions in the top ten category, three institutions were from USA, and the other seven were from the Far East.

Again, the ranking of research institutions by first-author articles, *FPR*, and corresponding-author articles, *RPR*, was strongly correlated to their total research output (*TPR*) (r^2 = 0.925 and 0.910, respectively). As in the ranking of most productive countries, the *SPR* (%) of the institutions was independent of *TPR* (r^2 = 0.268). The volume of articles produced by the ten most productive institutes followed the order: *NCPR* (%) >*ICPR* (%) >*IPR* (%). This showed that tea research became increasingly collaborative over this period.

Analysis of keywords

In recent years, a bibliometric research method in which the distribution of keywords at different periods could be employed in the study of research trends in various fields has been presented (Xie *et al.*, 2008).

Analysis of title-words

The title of an article normally contains the information that the authors desire most to express to the readers. We, therefore, analysed recurrence of title-terms in tea research by four 6-year periods from 1991 to 2014. Fifty title-words were found, which recurred in at least 498 different tea research articles over the period of study. The searching term 'tea' occurred 8459 times, followed by the terms: 'green' (3035), 'effect' (2489), 'effects' (2313), 'activity' (1855), 'cells' (1817), 'human' (1497), 'antioxidant' (1464), 'determination' (1251), 'cancer' (1247), 'extract' (1080), 'rat' (1069) and 'polyphenols' (1031). The type and order of frequently used title-terms for the entire (1991–2014) period were different from the most frequent title-terms for the initial 6-year (1991–1996) period. The terms 'potassium', 'rat', 'K^+' and 'channels' featured less prominently in recent years. These four terms showed a progressive fading trend towards 2014 with the term 'K^+', for instant, vanishingly ranking 6th, 10th, 98th and 275th in 1991–1996, 1997–2002, 2003–2008 and 2009–2014 6-year periods, respectively. Similar trends would be found for the other three terms, which indicating that relevant research received less attention or usage habits of words changed.

Conversely, the corresponding ranking for each of the terms in the overall list of most popular title-words including 'tea' (1st, 1st, 1st and 1st), 'green' (10th, 2nd, 2nd and 2nd), 'effects' (2nd, 3rd, 3rd and 3rd), 'effect' (5th, 4th, 4th and 4th), 'activity' (16th, 6th, 6th and 7th) and 'cells' (8th, 5th, 5th and 7th) remained relatively unchanged over the respective periods. Furthermore, there were certain title-terms including 'antioxidant' (119th, 18th, 9th and 5th); 'cancer' (65th, 11th, 10th and 9th); 'extract' (142nd, 47th, 12th and 8th); 'risk' (80th, 45th, 36th and 32nd); 'mice' (71st, 62nd, 31st and 30th) and 'oxidative' (177th, 86th, 43rd and 33rd) that progressively improved in usage frequency over the respective 6-year periods. The latter set of terms gained prominence in tea research at the expense of the former list of title-terms. It shows that there was a focal shift in tea research from 1996, which also explains the observed 'bi-sigmoid' shape of the curve in the figure.

Author keywords

Author-supplied keywords offer information about research trends that concern researchers. At least fifty terms were found within author-supplied keywords that recurred, as a minimum, 117 times in tea research articles from 1991 to 2014. Again, the searching term 'tea' (1599 times) was the most frequent (Table 3), followed by 'green tea' (1319), 'polyphenols' (690), 'antioxidants' (627), 'catechins' (612), 'caffeine' (570),

'EGCG' (554), 'camellia sinensis' (543), 'catechin' (541) and 'flavonoids' (515). Some of them confirmed the results of the title-words analysis. The terms 'tea' and 'green tea' were the top two positions each year from 1997 to 2014. The 15th position 'black tea' with decreasing trend is one of the most common tea types taken by many people around the world. Repetitive occurrence of the terms 'green tea', 'green' and 'tea' in title-words and author keywords with increasing trends meant that green tea was the object of most frequent inquiry in tea science during this period, instead.

Notably, the terms 'epigallocatechin' (210) and 'antioxidant capacity' (133) did not feature in the fifty most frequent author-supplied keywords during 1991–1996 period. Nonetheless, the terms relating to 'green tea', 'antioxidants', 'flavonoid', 'polyphenols', 'catechins' and 'EGCG' occupied the top fourteen positions in the list of the most frequently used author keywords from 1991 to 2014. The fourteen terms became progressively significant to tea research from 1997 onwards. It showed that these terms became the focal point in the re-awakening of global tea research after the year 2002.

KeyWords Plus

KeyWords Plus, which supplied additional search terms, was extracted from the titles of papers cited by authors in their bibliographies and footnotes in the Web of Science database (Garfield, 1990). The *KeyWords Plus* analysis as an independent supplement reveals the contents of the articles with more details. At least fifty terms were found among the *KeyWords Plus*, which appeared 381 or more times within tea research articles published during the period under study. The overall most frequent terms in this category were 'green tea' (3361 times), 'polyphenols' (1628), 'tea' (1539), 'in-vitro' (1535), 'inhibitions' (1516), 'cells' (1210), 'black tea' (1192), 'catechins' (1159), 'cancer' (1098), 'expressions' (1092) and 'flavonoids' (1031). Of these terms, only the terms 'inhibitions' and 'cells' also appeared in the top ten category of *KeyWord Plus* terms during the initial 1991–1996 period. The top ten most frequent terms within this category did not change significantly between 1997 and 2014 but improved in frequency over the entire study period instead.

The most repetitive terms among the articles' title-terms, author keywords and *KeyWords Plus* indicated the themes of most cited articles in tea science during the 1991–2014 period (Hertog *et al.*, 1993; Yen & Chen, 1995; Scalbert & Williamson, 2000). In an article by Yen & Chen (1995) with TC_{2014} of 840, for example, the terms 'tea' (thirteen times), 'green tea' (twenty-seven times), 'antioxidant (thirty times)' and 'polyphenol' (five times) occur in all article parts. These trends show that the terms that gained prominence in all parts of the articles were associated with biochemical dietary effects of active ingredients tea products. Tea research during this period was, therefore, focused on the chemistry and biochemical activities of components in tea products in relation to mitigation of emergent health challenges of the 21st century.

Most terms under the top categories of title-words, author keywords and in *KeyWords Plus* were related to the active ingredients of tea products and their biochemical dietary effects. The current analysis therefore suggests that tea research during this period in time was more focused on the compositional chemistry of tea products and on the biochemical activities of components in tea in relation to mitigation of emergent

Table 4 Top ten articles ($TC_{2014} > 740$)

Rank (TC_{2014})	Rank (C_0)	Rank (C_{2014})	Rank (TCPY)	Title	References
1 (2664)	6760 (0)	6 (81)	1 (121)	Dietary antioxidant flavonoids and risk of coronary heart disease – the zutphen elderly study	Hertog *et al.* (1993)
2 (1071)	2459 (1)	11 (69)	3 (71)	Dietary intake and bioavailability of polyphenols	Scalbert & Williamson (2000)
3 (991)	77 (7)	21 (54)	9 (50)	The relative antioxidant activities of plant-derived polyphenolic flavonoids	Riceevans *et al.* (1995)
4 (925)	8 (18)	34 (44)	2 (77)	The specificities of protein kinase inhibitors: an update	Bain *et al.* (2003)
5 (865)	32 (9)	108 (28)	13 (46)	Identification of epoxyeicosatrienoic acids as end othelium-derived hyperpolarizing factors	Campbell *et al.* (1996)
6 (840)	2459 (1)	8 (75)	18 (42)	Antioxidant activity of various tea extracts in relation to their antimutagenicity	Yen & Chen (1995)
7 (833)	2459 (1)	68 (33)	25 (38)	Intake of potentially anticarcinogenic flavonoids and their determinants in adults in the Netherlands	Hertog *et al.* (1993)
8 (773)	6760 (0)	392 (16)	21 (39)	Polyphenolic flavanols as scavengers of aqueous-phase radicals and as chain-breaking antioxidants	Salah *et al.* (1995)
9 (748)	2459 (1)	16 (60)	37 (33)	Green tea composition, consumption, and polyphenol chemistry	Graham (1992)
10 (747)	2459 (1)	6 (81)	5 (57)	Free radicals, antioxidants, and nutrition	Fang *et al.* (2002)

health challenges of the 21st century. It is not surprising, therefore, that the highest volumes of literature in tea research appeared to originate from the tea-consuming countries of the Far East, Europe and North America (Table 1).

Most cited articles

Even though a great many articles have been published in tea research since the early 1990s only a small number of the articles account for a huge proportion of citations within the 1991–2014 period. In order to gain further insight into the subjects that bore significance to tea research during this period, the top ten most cited articles were analysed. The ten most cited articles accounted for over 10 457 citations in this period (Table 4). The most cited article (TC_{2014} = 4202) was published by Doyle *et al.* (1998), which was published in *Science* (journal IF_{2014} = 6.99). This article does not, however, fit in tea science because it was included in the searches on account of the term 'TEA', which in its context, is an acronym for 'tetraethylammonium'. Therefore, this article was excluded for the analysis of most cited articles.

Biochemistry and molecular biology (three articles), nutrition and dietetics (three articles) were the most prominent subject categories, followed by general and internal medicine (two articles), and environmental and occupational health public, multidisciplinary agriculture, biophysics, oncology, cardiac and cardiovascular systems, applied chemistry and haematology with only one article, respectively. Thus, all the top ten highly cited titles concerned antioxidant inhibitive effects of polyphenolic flavonoids in tea. This affirmed earlier postulates that the observed reawakening in tea research after the year 2002 was occasioned by a focal shift from classical tea research to the chemical and biochemical attributes of tea products at their point of consumption.

Analysis of top publication journals and Web of Science subject categories

Evaluation of subject categories divulge information that can be useful in the examination of bibliographic trends of journal publications, citations and performances highly cited journals and papers (Chuang *et al.*, 2011b). The most published journals in tea research during 1991–2014 were analysed. The most published journal in tea research was *Journal of Agricultural and Food Chemistry* (with 984 articles), followed by *Food Chemistry* (662), *Journal of Physiology-London* (267), *Bioscience, Biotechnology and Biochemistry* (250), *Food and Chemical Toxicology* (232), *Journal of the Science of Food and Agriculture* (217), *Journal of Chromatography A* (200), *PLoS One* (193), *Journal of Nutrition* (177), and *Food Research International* (175). Seven of these journals were listed in the Thomas Reuters Web of Science under the subject category of 'agriculture, biology and environment'. Only one journal each appeared under: 'physical, chemical and earth sciences'; 'life sciences'; and 'zoological records', respectively.

There was no correlation (r^2 = 0.000) between the number of publications and the cumulative impact factors (IF_{2014}) of most published journals. The choice of journals for communicating tea research was not, therefore, dictated by scientific repute of the publishers but rather by relevance to the research themes and target audience.

To understand publication trends among the subject categories, a relationship between number of publications in the categories and publication years has been presented (Sun *et al.*, 2012). The analysis of the publication trends in the top five most published subject categories revealed that the key subject categories in tea science during this period were as follows: 'food science and technology' (TP = 5110), 'pharmacology and pharmacy' (TP = 2983), 'applied chemistry' (TP = 2704), 'biochemistry and molecular chemistry' (TP = 2696) and 'nutrition and dietetics' (TP = 2479).

After the initial rise in the number of research output from just 25 articles in 1991 to 132 articles in 2002, the rate of publication output under the subject category of 'food science and technology' increased to 529 articles by 2014. Similar incremental trends in the rate of publication of tea research articles were witnessed under subject categories of 'nutrition and dietetics' and, to a limited extent, in 'applied chemistry'. These trends appeared to affirm that food science was the central theme in tea research during the period of the present analyses.

Conclusion

This study explored bibliometric analysis of tea research in the world. Important features and trends in science and performance research institutions during the period for 1991 to 2014 have been unearthed. English was the main language of tea research, but twenty-one other languages also featured. Increasingly, more researchers, institutions and countries got involved in tea research over this period. It has been demonstrated that although both the USA and Japan had long-standing prominence in tea research, the observed reawakening that characterised this study field from 2002 to 2014 was spearheaded by the tea-producing countries of the Far East, namely China and India. It was revealed that this renaissance coincided with a focal shift where the health aspects of food science took a more central role in tea science over classic tea research after the year 1997. These analyses disclose trends that could be applied in

discerning the direction of science as basis for deciding strategic research in tea science in the subsequent periods of study.

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