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Global Warming and Tea Production—The Bibliometric View on a Newly Emerging Research Topic

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Abstract: In this study, we analyzed the newly emerging research field of climate change in combination with tea production. We adapted a valid search query to cover the relevant literature as completely as possible and to exclude irrelevant literature. The search resulted in a publication set of 14 key papers dealing with the implications of climate change for tea production as well as 71 papers citing at least one of the 14 key papers. The VOSviewer software was used for revealing the thematic content of the publication set based on the analysis of the keywords. The analysis illustrates the importance of climate change for tea production and mirrors the emerging discussion on climate change impacts and adaptation strategies. Questions regarding the historical context of research fields or specific research topics can be answered by using a bibliometric method called "Reference Publication Year Spectroscopy" (RPYS). The standard RPYS, as well as RPYS-CO, which is based on co-citations of a marker paper, were applied and the most important publication in the historical context of climate change in combination with tea production was identified: both RPYS analyses revealed a paper by M.A. Wijeratne working at the Tea Research Institute (TRI) in Sri Lanka as the starting point of the newly emerging research topic. Currently, the research topic is stimulated by research projects and publications of Selena Ahmed at the Montana State University (USA).

Keywords: climate change; tea production; citation analysis; RPYS

1. Introduction

The many indications of global warming have attracted strongly increasing attention in the sciences. Scientists try to understand past climate and to predict future climate by using observations and theoretical models. The scientific community has contributed extensively with various data, discussions, and projections on the future climate, as well as on the effects and risks of the expected climatic change [1–3]. Climate is one of the key controlling factors in agriculture, since most crops are very responsive to their surrounding environment. Anthropogenic climate change due to CO_2 and other human-generated greenhouse gases is anticipated to affect agriculture all over the world, having both positive and negative effects (e.g., impacts on food production and food security).

Climate has always been a decisive factor in agriculture and crop production, respectively. Not surprisingly, agriculture and food security have become main topics of current climate change research [3]. In a recently published study, Marx et al. have analyzed the emergence of climate change research in combination with viticulture from a bibliometric (quantitative) perspective [4]. Besides grapevine (*Vitis vinifera*), tea (*Camellia sinensis*) is another natural beverage which is sensitive to climate change. Several findings indicate that climate change seems to negatively affect also tea production [5]. However, the research investigating the effect of anthropogenic climate change on tea production has just started to emerge; currently, there are much less than 100 papers available covered by the Web of Science (WoS, Clarivate Analytics) database. For comparison: Marx et al. found more than 1000 papers in the case of climate change and viticulture [4].

2. Research on Tea Production and the Objectives of this Study

Tea is one of the most popular and lowest cost beverages in the world and has become the second-most consumed liquid (after water). According to Dutta, China is the largest producer of tea, followed by India, Kenya, and Sri Lanka [6]. The Yunnan Province in South China, the motherland of the tea plant (*Camellia sinensis*), has an extensive history of cultivating tea. Tea production plays a key role in the economy of Sri Lanka and is of major importance for regional economies of India, in particular for the key production regions Assam and Darjeeling. For example, Assam contributes around 17% of world tea production, supporting the livelihoods of around 1.2 million laborers [7]. In South Sri Lanka, tea dominates the landscape and generates income for over 1 million people [8].

The tea plant grows in a variety of climates and it is difficult to specify an ideal climate. The monsoonal climate of Northeast India with alternate wet and dry seasons and the high elevation of subtropical mountains in China, India, and Sri Lanka provide optimal conditions for tea production. Despite of the variety of climates, tea production relies on suitable temperatures and well distributed rainfall. The specific climatic niche makes the growing of tea bushes vulnerable to climate change. Thus, global warming is expected to have a significant impact on tea production and presumably will influence both the quantity and quality of tea [5–8].

Recent research on anthropogenic climate change revealed that the weather is becoming more extreme and intense, more erratic and less predictable: longer dry periods; heavier downpours over many days; more hail; and cyclonic storms [1–3]. The rainfall pattern and the average and maximum temperatures in all main tea production regions seem to have undergone marked changes in the recent past [6]. The tea plants are affected by both excesses and shortages of water and suffer from increased climatic stress. Changing climate conditions impact the concentration of secondary metabolites, which are most important for the quality of tea. The dilution of phytochemicals as a consequence of more frequent extreme rains seems to explain the changes of the tea taste that tea farmers in Yunnan (South China) are experiencing [9–11]. According to recent findings in the Jiangxi Province (Eastern China), rising temperatures may deteriorate tea quality [12].

Climate change is expected to decrease not only the quality of tea, but also the quantity of tea production: as a consequence of increased soil erosion, pests, and diseases that are becoming more resistant [5]. Generally, a moderate increase in temperature increases the tea yield. However, above an optimal temperature a further temperature increase seems to reduce the productivity of tea plantations [6,13,14]. Given the importance of the tea crop to the main production regions, this may result in negative economic and social consequences, particularly for tea farmers, workers on tea estates, and tea traders. Tea farmers are faced with the need of climate change adaptation strategies for their future tea production. Most authors of the relevant publications agree that more studies in this area are needed.

This study has three objectives: first, we identify the relevant publications of research on climate change and tea production; second, we search for publications which are most important for the evolution of this newly emerging research field; third, we discuss influential papers on the field published in more recent years.

3. Materials and Methods

3.1. Dataset Used

For the two preceding bibliometric analyses of the overall climate change related publications, we developed a sophisticated search query to cover the relevant literature as completely as possible [15,16]. For the previous analysis of climate change research and viticulture, we extended the query to focus on the literature of this specific research topic within climate change research, resulting in more than 1000 publications [4]. The new modification of the query for searching the publications dealing with climate change (global warming) and tea resulted in 162 publications (see the WoS search query in the appendix). However, further inspection of this publication set revealed that there are many non-relevant publications:

1. Some publications deal with climate change and agriculture; tea is only mentioned casually (e.g., tea waste for biogas production).
2. Some publications discuss the increase of malaria among workers on tea estates as a consequence of global warming.
3. The American Tea Party (a conservative political movement) is heavily involved also in the scientific global warming discussion.
4. TEA is the acronym for the substance Triethanolamine, which plays a role in the removal of carbon dioxide in aqueous solutions.

Further refinement of the search query was not promising, since the search options of literature databases are limited (e.g., abbreviations cannot be distinguished from words). Therefore, we have manually selected 14 key papers out of the retrieved publication set dealing primarily with climate change or global warming and tea (*Camellia sinensis*). We extended this small publication set by including the 71 papers citing at least one of the 14 key papers. The citing papers mostly deal with the same topic and contain additional references relevant for the research topic analyzed here. However, many are not retrieved through application of our search query for one reason or another (e.g., [17,18]; see discussion section). Thus, the inclusion of the citing papers of the key papers ensures a higher degree of completeness.

The overall set of 84 publications (comprising the 14 key papers listed in Table 1 and their 71 citing papers, with 1 overlapping paper) dealing with the implications of climate change for tea production was searched in the WoS database (date of search: 1 June 2017). The publications retrieved do not comprise the complete publication set covering any relevant research paper. There are presumably more papers which appeared in journals not covered by the WoS (and also books or book chapters). However, we assume that we have included the (journal-based) key papers dealing with research on climate change and tea production. Since researchers in the sciences and engineering are (increasingly) publishing their research results in peer-reviewed journals, it is reasonable to use this database for our study [19].

3.2. Visualization of the Research Topic

The method which we used for revealing the thematic content of our publication set is based on the analysis of all keywords: author keywords and "keywords plus" (allocated by the database producer). We used the VOSviewer software 1.6.5 for mapping the keywords of the climate change research and tea literature (see http://www.vosviewer.com) [20]. The produced keyword map is based on concurrent occurrence (co-occurrence) for positioning the nodes (in our case: the corresponding keywords) on the map.

3.3. Cited References Analysis

Questions regarding the historical context of research fields or specific research topics can be answered by using a bibliometric method called Reference Publication Year Spectroscopy (RPYS) [21], preferably in combination with a recently published program named CRExplorer (see http://www.crexplorer.net) [22,23]. In this study, we determined which references have been most frequently cited by the papers in our publication set on climate change and tea production.

The analysis of the publication years of the references cited by all papers in a specific research field (here: climate change and tea) shows that publication years are not equally represented. Some years occur particularly frequently among the cited references. The years appear as pronounced peaks in the distribution of the reference publication years (i.e., the spectrogram). The peaks are frequently based on single publications which are highly cited compared to other early publications. The highly cited papers are—as a rule—of specific significance to the research field in question (here: climate change research and tea) and in the case of earlier publications often represent its origins and intellectual roots [21]. In recent years, several papers have been published, in which RPYS is basically described and applied to examine the historical roots of various research fields [4,16,24,25].

Recently, we applied RPYS to reveal, (1) which early works are cited most frequently in the overall climate change research literature [16] and (2) in the more specific research topic dealing with climate change and viticulture [4]. In this study, we present an analysis of climate change and tea production as another more specific research topic in the context of climate change research. We performed the reference analysis by importing the climate change and tea publication data including the cited references (downloaded from the WoS) into the CRExplorer. The first step in RPYS is to select the publications of the research field and to extract all references cited therein. The second step is to establish the distribution of the frequencies of the cited references over the reference publication years and to determine those years cited rather frequently. The third is to analyze the years for frequently cited publications.

The RPYS analysis reveals the most frequently cited (referenced) papers within specific reference publication years. RPYS does not identify the most highly cited papers of the publication set under study (as usually done by bibliometric analyses in research evaluation). The RPYS analysis aims to mirror the knowledge base of climate change and tea production.

In this study, we present the results of a standard RPYS and a RPYS-CO on climate change research and tea production. The RPYS-CO is based on a restricted set of cited references, which are co-cited with a specific cited reference [16]. We included in the study (1) the total number of references (n = 5507) cited within our publication set (n = 84) and (2) the co-cited references (n = 1326) of a specific historical paper (see below).

3.4. Analysis of the Publication Set: Standard RPYS

The reference publication years for the standard RPYS range from 1927 to 2016. The CRExplorer offers the possibility to cluster and merge variants of the same cited reference [22,23]. Clustering the reference variants by considering volume and page numbers and subsequent merging aggregated only 5 out of 5507 cited references. In our experience, older cited references are more prone to "mutation" and more reference variants can be found. Since most cited references analyzed here appeared after 2000, cited references variants are not a significant problem.

3.5. Publications Citing a Marker Paper: RPYS-CO

Since only a small portion of the publications in a specific field normally discusses its historical background, a kind of dilution or weakening happens with regard to the appearance of historical references: among the multitude of cited references, only the very prominent and most cited early works appear as distinct peaks in the RPYS. To overcome this problem, the RPYS-CO was introduced, which is based on the co-citation analysis [16,26]. The method takes advantage of the fact that concurrently cited (co-cited) papers are more or less closely related to each other. One can select the citation environment of specific references in the form of all co-cited references and analyze these references applying RPYS-CO. The specific references are used as marker or tracer references. We assume that papers citing the selected references are potential candidates for citing also many other references relevant in a specific context. For the RPYS-CO in this study, we selected the paper by M.A. Wijeratne entitled "Vulnerability of Sri Lanka tea production to global climate change" [5], which has been cited 25 times (2 misspelled citations have been included) until 1 June 2017. This publication is the earliest key paper selected manually and received the largest number of citations.

4. Results

4.1. The Key Papers and Their Citing Papers

Table 1 presents the 14 key papers dealing with climate change and tea production, which we selected from the initial publication set of 162 papers. The publications by Wijeratne [5,13] discuss the impact of climate change on tea production in Sri Lanka, whereas the papers by Ahmed [9,10,27] focus on the impact of climate change on tea quality in general. The other key papers deal with the impact of global warming on the tea production in South China [12,28–30], Northeast India [6,7], Sri Lanka [14], and Eastern and South Africa [31–33]. Some additional and highly relevant publications have been identified by considering the citing papers and by reference analysis via RPYS (see below).

Note that the citation counts of papers published in different years are not comparable with each other. Also, most papers appeared during the recent few years and hardly had a chance to accumulate many citations.

In his seminal 1996 paper Wijeratne [5] analyzed the relationship between climatic factors and tea yield, in particular the effect of temperature on the shoot extension rate. He found that the shoot extension rate increases with increasing temperatures only up to 22 °C, but further increases in temperatures result in a decline. Wijeratne expects the adverse effects of climate change to be greater in the low elevation tea growing regions, where the majority of tea production enters the market. This paper also discusses the consequences of the predicted recurrent warm seasons, droughts, and heavy rains for the tea production in Sri Lanka: in particular the vulnerability to soil erosion and outbreaks of pests. To mitigate economic problems, Wijeratne suggests an adaptation strategy to minimize the adverse effects of global warming on the tea industry in Sri Lanka. In a follow-up paper published in 2007 (a key paper detected by RPYS, see below), Wijeratne et al. [13] assessed the impact of climate change on the productivity of tea plantations in Sri Lanka. The authors concluded that (1) increasing temperatures are likely to reduce tea yields at low elevations and (2) low and mid elevations are more vulnerable to the adverse impact of climate change.

The key paper by Archer et al. [31] appeared more than a decade later than the earliest key paper [5]. The authors describe the implications of climate change for small-scale rooibos tea (*Aspalathus linearis*) farmers in western South Africa and discuss the ways in which farmers are adapting to current climate variability. The study underlines the substantial experience of farmers in adapting to adverse climate conditions and maps out existing adaptation strategies. The authors suggest to combine external knowledge with the indigenous adaptive capacity as a starting point for adaptation strategies. Lou et al. [28] analyzed the pick beginning date and frost damage risk trends of three tea varieties in the Longjing tea production area in China. They used meteorological data from 12 stations over the period 1971–2010. The authors found increasing annual mean temperatures for all regions. The pick beginning date of one tea variety (Jiukeng, a local traditional variety) shows a statistically significant trend toward earlier dates since 1990. Most regions show no statistically significant frost damage risk trends for all varieties. A subsequent analysis by Lou et al. [29] reveals that the economic outputs and benefits during the main tea producing periods have decreased significantly for tea plantations (in contrast to family farms) of one specific tea variety (Longjing-43).

Table 1. List of 14 key papers dealing with climate change and tea production including the number of citations (times cited) until present (source: WoS, date of search: 1 June 2017). The papers are sorted by publication years in ascending order.

#	Paper	Times Cited	Ref.
1	Wijeratne, M.A.: Vulnerability of Sri Lanka tea production to global climate change. Water, Air, and Soil Pollution 92(1–2), 87–94 (1996).	25	[5]
2	Archer, E.R.M., Oettle, N.M., Louw, R., Tadross, M.A.: 'Farming on the edge' in arid western South Africa: climate change and agriculture in marginal environments. Geography 93, Part 2, 98–107 (2008).	20	[31]
3	Lou, W.P., Sun, K., Sun, S.L., et al.: Changes in pick beginning date and frost damage risk of tea tree in Longjing tea-producing area. Theoretical and Applied Climatology 114(1–2), 115–123 (2013).	5	[28]
4	Ahmed, S., Orians, C.M., Griffin, T.S., et al.: Effects of water availability and pest pressures on tea (*Camellia sinensis*) growth and functional quality. ABO Plants 6, plt054 (2014).	6	[10]
5	Dutta, R.: Climate change and its impact on tea in Northeast India. Journal of Water and Climate Change 5(4), 625–632 (2014).	0	[6]
6	Ahmed, S., Stepp, J.R., Orians, C., et al.: Effects of extreme climate events on tea (*Camellia sinensis*) functional quality validate indigenous farmer knowledge and sensory preferences in tropical China. PLoS One 9(10), e109126 (2014).	14	[27]
7	Lou, W.P., Sun, S.L., Wu, L.H., Sun, K.: Effects of climate change on the economic output of the Longjing-43 tea tree, 1972–2013. International Journal of Biometeorology 59(5), 593–603 (2015).	2	[29]
8	Larson, C.: Agricultural Research - Reading the tea leaves for effects of climate change. Science 348(6238), 953–954 (2015).	1	[11]
9	Adhikari, U., Nejadhashemi, A.P., Woznicki, S.A.: Climate change and eastern Africa: a review of impact on major crops. Food and Energy Security 4(2), 110–132 (2015).	10	[32]
10	Boehm, R., Cash, S.B., Anderson, B.T., et al.: Association between empirically estimated monsoon dynamics and other weather factors and historical tea yields in China: results from a yield response model. Climate 4(2), 20 (2016).	5	[30]
11	Ochieng, J., Kirimi, L., Mathenge, M.: Effects of climate variability and change on agricultural production: the case of small scale farmers in Kenya. NJAS—Wageningen Journal of Life Sciences 77, 71–78 (2016).	3	[33]
12	Duncan, J.M.A., Saikia, S.D., Gupta, N., Biggs, E.M.: Observing climate impacts on tea yield in Assam, India. Applied Geography 77, 64–71 (2016).	0	[7]
13	Gunathilaka, R.P.D., Smart, J.C.R., Fleming, C.M.: The impact of changing climate on perennial crops: the case of tea production in Sri Lanka. Climate Change 140(3–4), 577–592 (2017).	0	[14]
14	Han, W.Y., Huang, J.G., Li, X., et al.: Altitudinal effects on the quality of green tea in east China: a climate change perspective. European Food Research and Technology 243(2), 323–330 (2017).	0	[12]

Ahmed et al. [10] examined the effects of water availability and pest pressures on tea leaf growth and secondary metabolites, using manipulative greenhouse experiments. In contrast to previous studies dealing with the impact of climate change on the tea production yield, this analysis focuses on tea quality. The results point to the dynamics of climate change effects on tea plants, indicating that pest pressures may offset the effects of changing precipitation conditions. The analysis by Ahmed et al. [27] deals with the effects of extreme climate events on tea quality. Such events are likely to become more frequent with climate change. The study is based on sampling of secondary metabolites during an extreme period of drought through the monsoon onset in a major tea producing area of China. The results are accompanied by tea farmer preferences on the basis of sensory characteristics and tea prices. The study validates farmer perceptions of extreme drought effects on tea quality. The authors suggest further research to better understand the interplay between climatic conditions and tea plants.

Dutta [6] analyzed the impact of future climate scenarios on tea production in Northeast India for 2050 based on the predictions of different models. The results demonstrate the possibility of an increase in average temperatures by 2 °C and a change of the tea production period, but not much variation in rainfall pattern. The authors state that with the expected impacts on tea production, the planters would need to make changes in their management practices to adapt to the changing climate. In a news article published in *Science* entitled "Reading Tea Leaves for Effects of Climate Change" Larson [11] discusses current research on the impacts of global warming on the quantity and quality of tea. The paper quotes Selena Ahmed and many other authors of papers mentioned above, without citing the papers explicitly. Adhikari et al. [32] published a review of impact on major crops in Eastern Africa. For coffee and tea as the major export crops, up to 40% yield loss is expected by the end of the 21th century (due to the reduction of suitable areas caused by temperature increase).

The paper by Boehm et al. [30] deals with the association between monsoon dynamics and historical tea yields in China. The study uses historical weather and tea production data from 1980 to 2011. The authors found that a 1% increase in monsoon retreat is associated with about 0.5% reduction in tea yield; a 1% increase in average daily precipitation during the monsoon period is associated with around 0.2% reduction in tea yield. Ochieng et al. [33] analyzed climate change impacts on revenue from crops in Kenya. The authors state that tea relies on stable temperatures and consistent rainfall patterns and any excess would negatively affect production. Duncan et al. [7] discuss the observing climate impacts on tea yields in Assam, India. They identified the tea yield response to climatic variability in tea plantations. The authors found decreasing tea yield returns to warmer monthly average temperatures. Drought intensity does not seem to affect tea yield, whereas precipitation intensity seems to affect tea yield negatively. The authors expect that increasing average temperatures will reduce the productivity of tea plantations.

Two very recent key papers deal with climate change perspectives for the tea production in Sri Lanka and the quality of green tea in East China: Gunathilaka et al. [14] analyzed the economic impacts of weather variations based on the panel data from 40 tea estates in Sri Lanka over a period of 15 years. Their findings show that a hotter and wetter climate will have a detrimental effect on tea production. Han et al. [12] studied the altitudinal effects on the concentration of substances which are most important for tea quality. The authors conclude that rising temperatures, particularly at lower altitudes, perhaps will deteriorate tea quality.

With the exception of Wijeratne [5], the key papers appeared after 2007, most of them in the last few years. This demonstrates how recent the analyzed research topic is. The recent IPCC Assessment Reports reveal the strong need of further research for improved predictions of the future climate [1–3]. The effects, impacts, and risks of climate change became increasingly obvious and more concrete. The discussion of the human induced climate change as a real phenomenon (at least for the vast majority of the scientific community, see [34,35]) obviously stimulated research on future pathways for adaptation of tea production.

The keyword map based on the 84 papers on climate change and tea production using the VOSviewer software is presented in Figure 1. The distance between two nodes (two keywords) is approximately inversely proportional to the similarity (relatedness in terms of co-occurrence) of the keywords. Hence, keywords with a higher rate of co-occurrence tend to be closer to each other. The size of the nodes is proportional to the number of papers with a specific keyword. The nodes on the map are assigned by VOSviewer to clusters based on a specific cluster algorithm (the clusters are highlighted in different colors). These clusters identify closely related keywords, where each keyword is assigned to only one cluster (the keywords were not unified concerning singular or plural ending and hyphens).

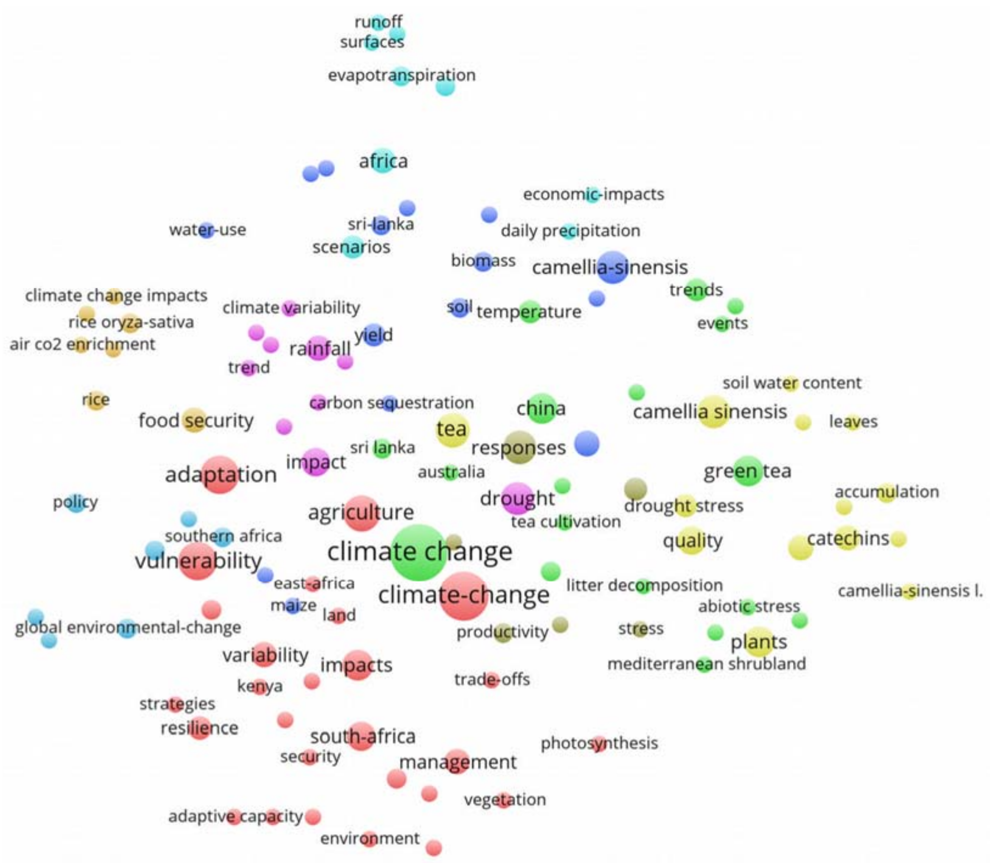

Figure 1. Co-occurrence network of keywords from 84 papers on climate change and tea production (the minimum number of papers containing a specific keyword is two).

As expected, our basic search terms *climate change* (*climate-change*) and *tea* (including the Latin name *camellia-sinensis*) appear in the VOSviewer map as pronounced keywords (center). They are surrounded by the terms *drought*, *rainfall*, *impact* (magenta colored cluster), *responses*, *quality*, *drought stress*, *heat stress*, *temperature*, and *trends* (mostly belonging to different clusters). All these keywords point to research dealing with the direct consequences of a warmer climate for tea production. The terms *adaptation*, *vulnerability*, and *impacts*, as well as (less pronounced) *management* and *variability* (all belonging to the red colored cluster) are major keywords implying research on the risks of climate change and mitigation strategies. Finally, three major tea producing countries (*China*, *South Africa*, and *Sri Lanka*) appear as keywords in the map. In summary, most keywords point to research dealing with the various problems of climate change for tea production.

4.2. Spectrograms of the Cited References

Figure 2 shows the result of the RPYS analysis. The spectrogram presents the distribution of the number of cited references across their publication years within the time period 1927–2016. The CRExplorer enables the identification of highly cited references in peak years via the table of references presented alongside the spectrogram.

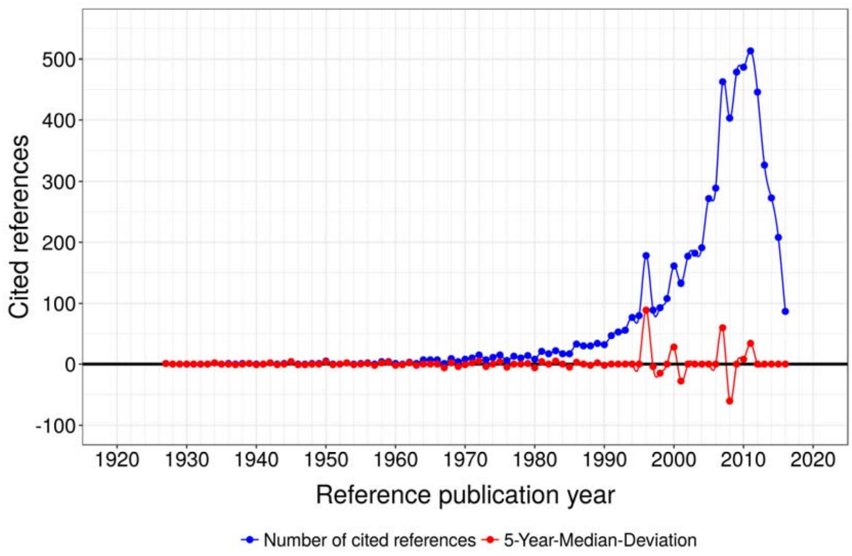

Figure 2. Annual distribution of the references cited in the publication set of 84 papers across their reference publication years 1927–2016. Blue curve: number of cited references; red curve: deviation from the median.

The blue curve in Figure 2 visualizes the number of cited references per reference publication year. In order to identify those publication years with significantly more cited references than other years, the deviation in each year from the median of the number of cited references in the two previous, the current, and the two following years ($t - 2$; $t - 1$; t; $t + 1$; $t + 2$) is visualized, too (red curve). This deviation from the five-year median provides a curve smoother than the one in terms of absolute numbers. We used both curves for the identification of peak papers.

Figure 3 shows the results of the RPYS-CO analysis based on co-citations of the seminal 1996 paper by Wijeratne [5]. The spectrogram presents the distribution of the number of cited references across their publication years within the time period 1927–2016.

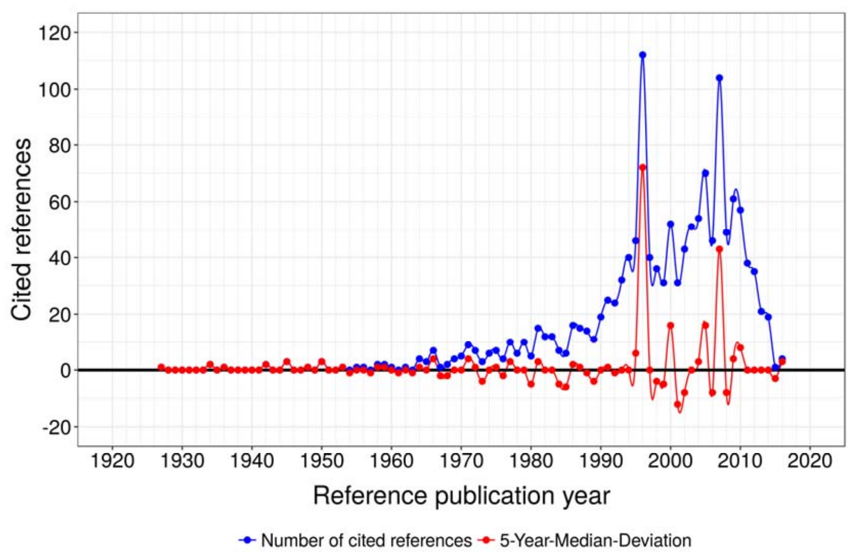

Figure 3. Annual distribution of the cited references, which are co-cited with the seminal 1996 paper by Wijeratne [5], across their reference publication years 1927–2016. Blue curve: number of cited references; red curve: deviation from the median.

According to Figure 2, there is only one single pronounced reference peak prior to 2000, corresponding to the paper by Wijeratne [5]. The pronounced appearance of this reference in the spectrogram is not surprising, since this publication is the most frequently cited paper among the key papers presented in Table 1. The question arises whether there are additional and in particular earlier papers which can be identified as the historical origin of the research topic analyzed here. We assume that such publications are co-cited with the paper by Wijeratne [5] and have therefore taken this paper as marker reference for the RPYS-CO analysis presented in Figure 3. By definition, the peak associated with this reference is dominating the result of the RPYS-CO analysis. Furthermore, Figure 3 shows no distinct peaks before 1996, when the paper by Wijaratne [5] appeared (the mini-peaks prior to 1996 result from a multitude of references with at most two citations each). Figure 3 reveals one further distinct peak corresponding to references published in the year 2007: another paper by Wijeratne [13], which appeared in the *Journal of the National Science Foundation of Sri Lanka* and is not covered as a database record by the WoS (only as reference, cited by other records), and two papers by de Costa [36,37]. One of these papers is co-authored by Wijeratne and is also not included in the WoS as database record, because the corresponding journal is not covered [37].

In this study, we retrieved the relevant literature on possible impacts of anthropogenic climate change on tea production using an approved query for literature searching in combination with RPYS. Due to the fact that the research field analyzed here is just emerging, the number of publishing and citing authors and papers, respectively, is limited. Therefore, the reference counts within the corresponding citation network are comparatively low, although all citations covered by the WoS are considered. As a consequence, the RPYS analysis is necessarily focused on the historical roots of the field. Nevertheless, we present in Table 1 the corresponding reference counts within our publication set of altogether 84 papers, which are identical with the total citation counts (times cited) in the WoS: the 71 citing papers comprise all relevant references covered by the database.

5. Discussion

The RPYS analysis, in combination with the CRExplorer, is a powerful method for exploring the cited references within a specific publication set, in order to detect the historical roots and other relevant publications and to track the evolution of the research field. The RPYS in this study is based on a publication set of 84 papers published between 1996 and 2017 dealing with research on climate change and tea production. The research topic has just started to emerge; currently, there are only less than 100 relevant papers available. Although the corpus of literature on the subject is low, the origin and the evolution of the research topic are not easily visible. The low number of highly relevant key papers was taken as a challenge for bibliometric analysis. We solved the problem by including 71 citing papers in the RPYS analysis.

The inclusion of citing papers enables the detection of relevant publications, which cannot be retrieved by topic searching for the following reasons: (1) some (cited) papers have no abstract texts available, but they are among the citing papers of the key papers; (2) the citing papers contain additional references relevant for the research field analyzed here (e.g., a contribution of a working group to the IPCC Report 2014 [18]); (3) some relevant papers appeared in journals which are not covered by the WoS (e.g., a key paper by Wijeratne was published in the *Journal of the National Science Foundation of Sri Lanka*, which has not been included in the WoS before 2008 [13]); (4) among the citing papers are reviews, which deal with climate change and agriculture and thus cannot be retrieved through application of our search query. However, they cite tea-related papers as specific examples, which can be included into the set of relevant publications (e.g., a paper entitled "Climate change and agriculture adaptation in Sri Lanka: a review" [17]).

The keyword map clearly reveals the importance of climate change research for tea production and for the discussion on climate change impacts and adaptation strategies. The RPYS analysis revealed a paper by M.A. Wijeratne working at the Tea Research Institute (TRI) in Sri Lanka as the starting point of the newly emerging research topic [5]. Currently, the research topic is stimulated by research projects and publications of Selena Ahmed at the Montana State University (USA) [10,27]. She established a large interdisciplinary research project with collaborations from Tufts University and the University of Florida on climate effects on tea quality and socio-economic responses [9]. The paper of reference [9] is also not covered by the WoS.

The key papers considered in this analysis include studies from different tea production regions based on different data and methods: historical weather data, predictions of climate models, greenhouse experiments (and their correlation with production yields), leaf growth rates, pick beginning dates, secondary metabolites, farmer preferences, revenue data, and others. Most authors take climate change more or less as a matter of fact and agree about the possible negative impacts of climate change on tea production yield and tea quality. Due to the few papers and the multitude of regions and methods applied, there are hardly any conflicting results. From the perspective of the cited references, there are four papers standing out with 10 or more citations until present [5,27,30,31].

Since most of the key papers considered here have been published recently (see Table 1), they had little chance to accumulate many citations until now. Also, the number of potential citers is low, because the corresponding research topic is new. Thus, their scientific impact is difficult to measure using citations. However, the oldest key paper [5] appeared in the RPYS and RPYS-CO analyses as the earliest distinct peak. Therefore, our RPYS analyses revealed this paper as the origin of the research topic. The 25 citations of this paper are delayed, compared to the classical citation distributions.

6. Conclusions

This bibliometric study quantified the publication output of research on climate change and tea production based on scientific journals covered by the WoS. The keyword analysis of the relevant publications illustrates the importance of climate change for tea production and mirrors the emerging discussion on impacts of climate change and adaptation strategies. The analysis of the cited references by RPYS revealed the starting point of the newly emerging discussion about the impact of global warming on tea production [5]. It is an advantage of RPYS that the seminal papers are detected on the basis of the references cited by the relevant community without any further assumptions. Considering that (1) most of the key papers appeared very recently and (2) tea production will continue to be a sensitive economic factor for many countries, we assume that this research field will be growing rapidly.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

WoS search query, date of search: 1 June 2017

# 6	162	#5 AND TS = (tea OR "*camellia sinensis*") Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan = All years
# 5	280,128	#3 OR #2 OR #1 Refined by: DOCUMENT TYPES: (ARTICLE OR PROCEEDINGS PAPER OR REVIEW) Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan = All years
# 4	306,824	#3 OR #2 OR #1 Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan = All years

# 3	129,607	TITLE: (climat* OR palaeoclimat* OR paleoclimat*) Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan = All years
# 2	71,792	TOPIC: ("global temperature*" OR "global warm*" OR "greenhouse effect" OR "greenhouse gas*" OR "greenhouse warm*") Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan = All years
# 1	197,108	TOPIC: ("climate chang*" OR "climatic chang*" OR "climate varia*" OR "climatic varia*" OR "climate warm*" OR "climatic warm*") Indexes = SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan = All years

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