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Global Trends in Research on Wild-Simulated Ginseng: Quo Vadis?

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Abstract: To the best of our knowledge, no study has systematically reviewed and analyzed the research trends of wild-simulated ginseng (WSG) used for food or medicinal purposes in many countries. WSG, a non-timber forest product, has been traditionally produced using agroforestry practices, and it has been consumed in various ways for a long time. WSG has a great demand in the market due to its medicinal effects, particularly in improving forest livelihoods and human health. Due to the significance of WSG, we conducted this research to explore the global research trends on WSG using systematic review methodology and keyword analysis. We used two international academic databases, the Web of Science and SCOPUS, to extract 115 peer-reviewed articles published from 1982 to 2020. The research subjects, target countries, and keywords were analyzed. Our results indicate four categories of WSG research subjects, namely growth conditions, components, effects on humans/animals, and the environment of WSG, and the case studies were mainly from the Republic of Korea, China, and the USA. Through topic modelling, research keywords were classified into five groups, namely medicinal effects, metabolite analysis, genetic diversity, cultivation conditions, and bioactive compounds. We observed that the research focus on WSG changed from the biological properties and cultivation conditions of WSG to the precise identification and characterization of bioactive metabolites of WSG. This change indicates an increased academic interest in the value-added utilization of WSG.

Keywords: wild-simulated ginseng; systematic review; keyword analysis; topic modelling; non-timber forest products (NTFPs); agroforestry

Citation: Shin, S.; Park, M.S.; Lee, H.; Lee, S.; Lee, H.; Kim, T.H.; Kim, H.J. Global Trends in Research on Wild-Simulated Ginseng: Quo Vadis?. *Forests* **2021**, *12*, 664. https://doi.org/10.3390/f12060664

Academic Editor: Martin Lukac

Received: 26 April 2021
Accepted: 17 May 2021
Published: 24 May 2021

1. Introduction

Ginseng obtained from plant roots has been used as herbal medicine for thousands of years. It has been recorded as an important medicine in the oldest medicinal herb book, Sinnongbonchogyeong (B.C. 3300) [1]. Before ginseng was cultivated, wild ginseng was collected and consumed as an edible herb. Increasing demand for wild ginseng resulted in the overexploitation of wild ginseng to meet the demands of the industrial market. Agroforestry practices have been used to cultivate wild-simulated ginseng (WSG). WSG is a perennial semi-negative, semi-annotated pericardium belonging to the genus "Panax" of the family Araliaceae. WSG has been used for food or medicinal purposes in many countries, including the Republic of Korea, China, Japan, Russia, and the USA [2]. WSG is known by different names, including WSG, wild-cultivated ginseng, mountain-cultivated ginseng, and forest-cultivated ginseng, among others. In this study, we use the term

WSG because it is officially used by the governments of the Republic of Korea, USA, and Canada [3–5]. We define WSG as the ginseng grown under trees in mountain areas via artificial transplantation of seeds or seedlings.

The active components of WSG can be largely divided into saponins (known as ginsenosides) and non-saponins (polyacetylenes, phenolic compounds, acidic polysaccharides, peptides, alkoxides, and amino acid derivatives), depending on the characteristics of chemical structures. Other components of WSG include volatile oil, sugar, starch, pectin, and minerals [6]. WSG contains many functional components that exert excellent effects on human health, such as anti-obesity activity [7], activation of the sympathetic nervous system [8], anti-fatigue activity [9], memory loss improvement [10], spatial cognitive ability improvement [11], cancer prevention, anti-cancer activity [12], and liver functional resistance [13]. Since the health effects of WSG are more recognized than those of cultivated ginseng [14], WSG is mostly produced only as a health supplement [15]. WSG is rarely cultivated for processing as a general food or cosmetic product due to the high production cost of WSG and difficulties in cultivation. However, due to the increasing interest and demand for eco-friendly non-timber forest products (NTFPs), WSG has gained attention as a high-value product. Due to the increasing production and demand, especially in the Republic of Korea [16], WSG has become a major source of income to forest communities. Thus, it is necessary to build scientific databases and accumulate research data for WSG [17].

Due to the greater use of WSG, many studies have been conducted on its growth conditions and characteristics. Many studies have also been conducted on farming locations [18], harvest, growth [19], effectiveness [7–13], and identification of genetic traits [20] and genome sequences [21]. Research trend analysis reflects academic orientation based on the aggregate results of integrating and analyzing key topics or values investigated in previous studies, such as medicine [22], education [23], forestry [24], and cultivated ginseng [25,26]. Such research trend analysis is valuable for diagnosing the current status and suggesting a direction for subsequent research needed to compensate for the knowledge gaps from individual research [27]. Moreover, industrialization of WSG requires a scientific and systematic approach considering the environment, location conditions, cultivation technology, efficacy, and environmental impact. Nevertheless, to date, no study has systematically reviewed and analyzed the research trends of WSG. Thus, this study seeks to examine the trends in WSG research using systematic review and topic modelling which have been widely used to analyze the recent research trends in linguistic, political, medical and biomedical, geographical science, etc. [28]. The study aimed to achieve answers to the following research questions: (1) What are the dominant keywords in the WSG study? (2) What is the main topic of the WSG study? The study findings can contribute to designing future studies on WSG, including the selection of topics.

2. Wild-Simulated Ginseng

2.1. History of Wild-Simulated Ginseng in the World

The family *Panax*, which comprises thirteen species, is extensively spread over East Asia to North America. *Panax ginseng* C. A. Meyer has been grown in Asian countries for thousands of years. *P. ginseng* is the only *Panax* species with a long history of cultivation [29]. The *Shennong Bencao Jing* (Shennong's Herbal Classic), a traditional document focusing on medicinal herbs, was written during the 1st century AD [30]. Ginseng has been artificially planted since the 15th century [30]. Since then, wild ginseng, which has been reseeded in the mountains or forest areas, has been cultivated and consumed as a herbal remedy [30]. There are historical documents on WSG in China and the Republic of Korea. The first book was *Do-gyeong-bon-Cho* (A.D. 1061), which was recorded in China as a bibliographic research on wild-simulated farming archives on ginseng during the reign of King Injong of the Song dynasty. The document focuses on the specific shapes of WSG throughout its growth cycle for four, five, and ten years [1]. During the rule of King In-Jong of the Koryeo Dynasty (A.D. 1122), some documents were written on artificially transplanted and reseeded ginseng [31]. During the Sejong era, wild ginseng has been reported in "Jiriji" (A.D. 1419–1450), which includes different characteristics of wild and cultivated ginseng. During the Sukjong era (A.D. 1675–1720), technological advancements in farming began to be prevalent through books on ginseng cultivation methods, including its distribution and accumulation, and the pervasiveness of ginseng agriculture was declared. Jeongjo Annal of the Jeongjo period (A.D. 1777–1800) documents the plantation of simulated ginseng near villages, thus highlighting its active expansion in communities [1].

Compared to WSG, studies on American ginseng (*P. quinquefolius*) have been conducted more recently [32]. Wild American ginseng was first discovered and cultivated in the New England forests in the early 1700s [33]; however, the farmers moved to a new area without a stable settlement. The cultivation of ginseng facilitated settlement in the region [33,34]. Harvesting and trading ginseng promoted economic growth [33]. Once the trade value was surprisingly high, a report stated that at least 64 million roots were exported in 1841 [35]. During the mid-1800s, WSG cultivation decreased significantly due to the transition of land from forest to farmland [33,35]. Forest degradation was accelerated in the 20th century, and thus it is difficult to harvest mountain ginseng, which grew on steep slopes [35].

2.2. Physiology and Growth of Wild-Simulated Ginseng

Ginseng grows and reproduces well with specific conditions: acidic or weak acidic soil (pH 4–6); 10–30° slope; sufficient nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and other organic contents [21]. As a perennial plant belonging to the genus *Panax*, WSG has similar physiological and growth characteristics to field-cultivated ginseng. However, WSG also has some unique characteristics. Both have main root, fine roots, and lateral roots. Main root is connected to the stem through rhizomes and the leaves are connected to the stem through leaf stalks [36]. However, they both have to be properly shaded for growth. The difference in the shading process is mentioned in the definition of WSG. Ginseng can be shaded using anthropogenic methods, whereas WSG must be shaded without any artificial measure. The biggest and most recognizable physiological characteristic is that WSG grows slower than field-cultivated ginseng, thus resulting in the smaller size of WSG. Furthermore, the photosynthesis rate is significantly lower in the leaves of WSG, mainly due to the cultivation environment, especially the lack of phosphorus in mountain soil [37]. The root volume is affected by the forest physiognomy of the cultivation area. In a mixed forest of soft and hardwood, the relationship between root volume and diameter at breast height (DBH) of surrounding trees shows a positive correlation [21]. The *Standard Manual for WSG Cultivation* from the Republic of Korea suggests that WSG should be cultivated in a mixed forest with trees having at least 15 cm breast height diameter and 10 m height for the overstory woods [38]. During proper growth conditions, WSG grows up to 92 mm (shoot) and 32 mm (root) in the second year and grows 187 mm (shoot) and 86 mm (root) in the fifth year [36]. In the Republic of Korea, 144 t of WSG (USD 36 million) was harvested in 2019 [39].

2.3. Effects of Wild-Simulated Ginseng

WSG has been regarded as a medicinal plant due to its significant functions [40]. The quality of WSG is considered superior to that of field-cultivated ginseng [37]. Furthermore, the biophysical activities of WSG are greater than that of ginseng [41]. For example, in skin cancer, ginseng has a chemopreventive effect, while WSG has a chemotherapeutic effect [41]. WSG shows diverse effects such as anti-oxidation [42], anti-inflammation [43], anti-tumor, and immune-enhancing activities [44]. Moreover, WSG has been used in the treatment of various health-related problems, including dry eye syndrome [45], obesity [46], high blood pressure [47], and cancer [48]. WSG has also been studied for human health and as a cosmetic due to its anti-wrinkle effect [42]. Additionally, many studies have reported the effects of WSG on the environment. Chowdhury and Bae [49] found some bacterial endophytes separated from WSG, which indicate significant inhibitory reactions against ginseng pathogens. Furthermore, some studies have reported an interconnection between mountain-cultivated ginseng and biodiversity [49–51]. Recent studies have shown that, due to the differences in anatomical structures and physiological conditions, different tissues of WSG retain diverse types of bacterial endophytes, and thus WSG transforms a wide variety of microbial communities [52]. Despite the benefits and effects of ginseng, which have been proven through various studies, few studies [37,53] have examined the effects of WSG. Thus, additional studies intensively focusing on the effects of WSG are needed.

2.4. Components of Wild-Simulated Ginseng

WSG comprises general components, such as water, crude fat, crude protein, crude ash, and nitrogen, and effective components such as crude saponin, including ginsenosides, polyphenol content, acid polysaccharides, and flavonoids. These WSG components have remarkable effects on blood pressure control, liver functions, anti-oxidation, anti-cancer, anti-diabetes, anti-inflammation, and anti-obesity effects [1,25,54,55]. Particularly, the polyphenol and flavonoid contents are related to anti-oxidation. The acidic polysaccharide content helps to boost immunity [54,55]. Ginsenoside, a type of glycoside combined to a glycone and aglycone, gets absorbed and transformed in the body to cause several benefits [54,56]. The components of WSG are closer to those of wild ginseng than to those of field-cultivated ginseng. The representative ginsenosides measured frequently are Rb1, Rb2, Rc, Rd, Re, Rf, Rg1, Rg2, Rg3, Rh2, F2, and CK. Rh2 and CK are not detected in cultivated ginseng, but they are detected only in wild ginseng and WSG [54,55,57]. The components of WSG vary with age, harvest time, and cultivation environment.

3. Topic Modelling

The explosive growth in structured/unstructured data and the development of methodologies for processing and analyzing such data have prompted interests in big data. Big data analysis is divided into data mining techniques with structured data, and text mining techniques with unstructured text data [58]. Text mining techniques determine the latent distribution of semantic patterns and topics from a text by classifying the unstructured text data into units that can be categorized in the computer’s analytical process [59]. The difference between text mining and traditional analytical methods is that the data for text mining is larger in scale and utilizes various language processing techniques. The main issue in text mining is how to analyze text rather than the amount of text to be analyzed. Thus, there is a growing interest in text mining, which is specialized in extracting keywords from text on a large scale and conducting statistical analysis in automated environments, called topic modelling [59].

Topic modelling methods for analyzing topics in documents include latent Dirichlet allocation (LDA), probabilistic latent semantic analysis (pLSA), and latent semantic indexing (LSI) [28]. Among them, the LDA method is most commonly used in the analysis of academic research trends [28]. LDA is based on LSI, but it is modified by supplementing the shortcomings of pLSA, which has the advantage of facilitating the identification of relationships between words and concepts [28]. Furthermore, LDA-based topic modelling effectively classifies words with different meanings into context, although the algorithm is simple and the word used is the same [60]. Most importantly, we can attempt to classify research topics, such that we can examine the overall distribution and composition of the topics and the potential topic structures in the study; additionally, we can capture related topics [60]. The LDA method also has advantages over content analysis as LDA-based topic modelling consists of a single document of several topics, each of which consists of a combination of words belonging to that topic [28,60]. For this reason, a single word can be used for multiple topics and not just for one topic. Thus, a document is a mixture of topics, and the topic is a mixture of words [61]. By aggregating the topics, we can also analyze them based on the LDA algorithm to identify the research trends in a particular work. In topic modelling, the number of topics is determined by the researcher, who performs several pre-checks to determine the number of topics, and all words in the document are sequentially arranged in descending order of probability values.

4. Materials and Methods

4.1. Data Collection (Identification)

We used two major databases, SCOPUS and the Web of Science, to search bibliographic information dealing with WSG collected up to October 2020. The first search was done under the title, abstract, and keywords of the paper itself, which includes WSG synonyms (Appendix A). This research follows the preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram [62], which has four steps, namely identification, screening, eligibility, and inclusion (Figure 1).

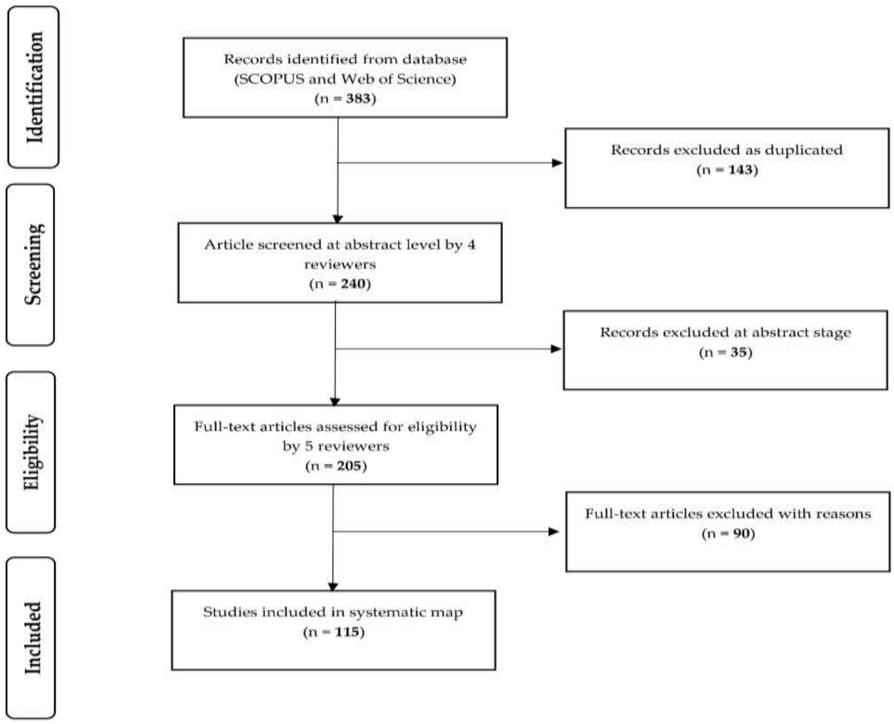


Figure 1. Preferred reporting items for systematic reviews and meta-analyses flow diagram.

4.2. Article Screening, Eligibility, and Inclusion

Three hundred and eighty-three articles collected from the identification stage were filtered through the next three stages, namely screening, eligibility, and inclusion. The literature search and selection were recorded independently by five coders, who compared the remaining records in each course [63]. Coders then screened the relevance of articles to WSG by reviewing the full text. Finally, a total of 115 articles of literature were used for the analysis (Figure 1).

4.3. Coding Strategy

A coding category system was developed to achieve the purpose of this study. After reviewing relevant literature, such as systematic reviews on cultivated ginseng [25,26,64], six categories were constructed, namely bibliographical data, study sites and fields, growth conditions, components, and effects on environment and animals (including humans), as stated previously in Section 2 (Table 1). This categorization was not designed to explore the quality/quantity but to examine general trends (e.g., WSG species, research fields, and publications years) and cause-and-effect relationships (e.g., WSG effect on human/animal or environments). By understanding the research trends in each category, we can determine the direction of WSG research. Five researchers independently coded, compared, and coordinated the results by discussing the mismatched data until reaching a consensus to increase the coding reliability.

Table 1. Coding category system.

Category	Sub-Category
Bibliographic data	Author, Title, Keywords, Abstracts, DOI, and Publication year.
Study site and fields	Country, Species, Farming area, and Study fields (Natural/Social).
Growth conditions	Site, Growth, Genetic diversity, Microstructure, Production, Photosynthesis, Age, Harvest, Pathogen/Disease, Season, and Fertilizer.
Components	Ginsenosides, Genome, Phenolic contents, Fatty acids, Proteins, Carbohydrates, Polyacetylene, Leaves, and Oligosaccharides.
Effects on environment	Soil, Carbon, Biodiversity, and Biocontrol.
Effects on animals (Humans)	Anti-oxidation, Anti-inflammation, Anti-cancer, Psychological (Stress), Obesity, Growth, Immune, Blood lipid profile, Alzheimer's Disease, Glycemic control, Semen, Fatigue, Tumor, Blood Pressure, Insulin Resistance, Liver function, Parkinson's disease, Diabetes, Dry eye syndrome, and Anti-apoptosis.

4.4. Topic Modelling

For topic modelling, this study utilized a list of keywords selected by researchers for topic modelling. Data preprocessing and cleaning are essential before starting LDA [60], as analysis results vary depending on the extracted keywords, or the author may choose unintended keywords, resulting in different results. To minimize the indexing effect of keywords extracted from the morpheme analysis process for data preprocessing, we refined the data by building dictionaries. Particularly, all keywords were reviewed to identify spacing, abbreviations, and word-form unification. For example, as the same words, "WSG" and "wild-cultivated ginseng", which are recognized as designated words with the same meaning, were in the same form to prevent them from being treated as different words when analyzing morphemes. Following this, we used term-frequency-inverse document frequency (TF-IDF) to avoid common errors that hinder the independent separation and grouping of keywords. By weighing words for information retrieval [64], the TF-IDF approach allows us to figure out the most frequent words in all documents, and those most likely to be indistinguishable to a specific topic group [65]. By using TF-IDF scores as a baseline, we extracted several words, including ginseng, wild ginseng, wild cultivated ginseng, *Panax ginseng*, ginsenoside, and antioxidant activities, to increase the independent topic distributions.

The number of topics in modelling is a major issue as it affects data interpretation [60]. The number of topics should be determined by focusing on the possibilities of interpretation of the analytical results and research purposes, rather than relying on probability values alone. During analysis, researchers run the LDA process and choose the number of topics, their iterations, α, β, and other values until topics are distinguishably divided [28]. In this regard, the researchers used a social network analysis software, NetMiner 4 [66]. For reasonable distributions of topic models, this study chose a set of parameters that affect the structure of word and topic distributions [60] with $\alpha = 0.01$, $\beta = 0.001$, and iteration = 10,000 times. After specifying five topics, all words in the papers were automatically calculated and arranged in each topic in descending order of their values, based on the main keyword of each topic with the highest probability. Further, linear regression analysis was conducted to identify the annual research trends in major topics.

5. Results

5.1. Article Distribution

The results indicate significant differences in the research on WSG, geographical imbalance (Figure 2), and specific period upsurge (Figure 3). First, the trends in publishing reveal three major countries, namely the Republic of Korea (56), China (25), and the USA (15), that have been actively conducting research on WSG. Approximately 73% of the total studies were published in the Republic of Korea and China. On the contrary, other countries such as Russia (3), Canada (2), and New Zealand (1) conducted relatively few studies on WSG. Figure 3 displays the fluctuation in the number of WSG studies since the first publication in 1982. After two reports in the 1980s, no article was published in the 1990s. The articles were published again between 2000 and 2001. The number of published articles increased from 2004. Most articles were published in the last 15 years. More than 50% of the studies were published after 2016, and most studies were published in 2019.

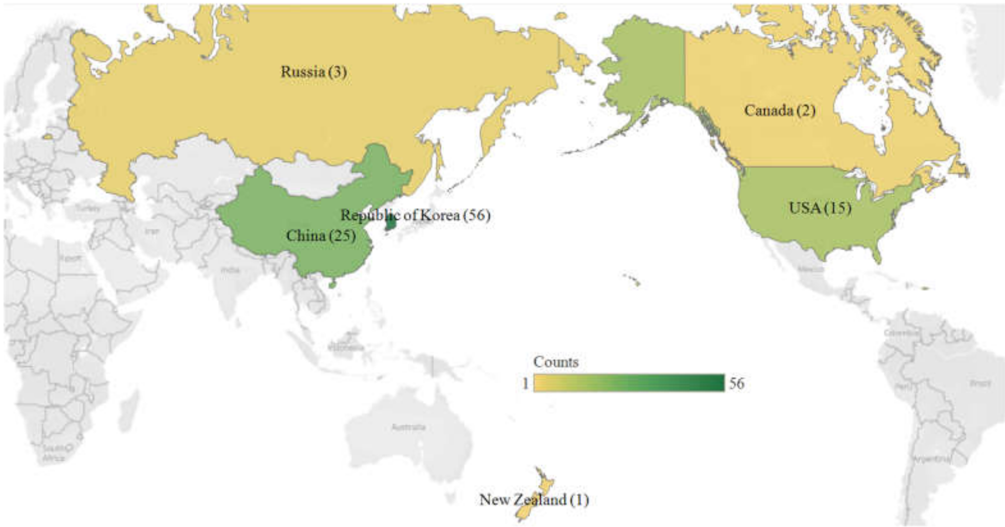


Figure 2. Geographic distribution of wild-simulated ginseng articles. The darker the green color, the higher the number of articles. This figure excludes five articles including more than one country cases and eight articles without specific country case (N = 115).

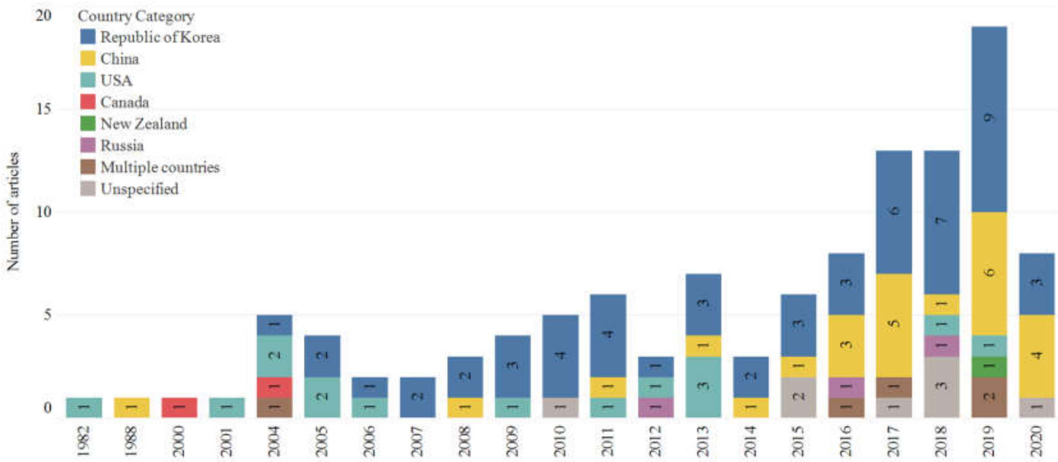
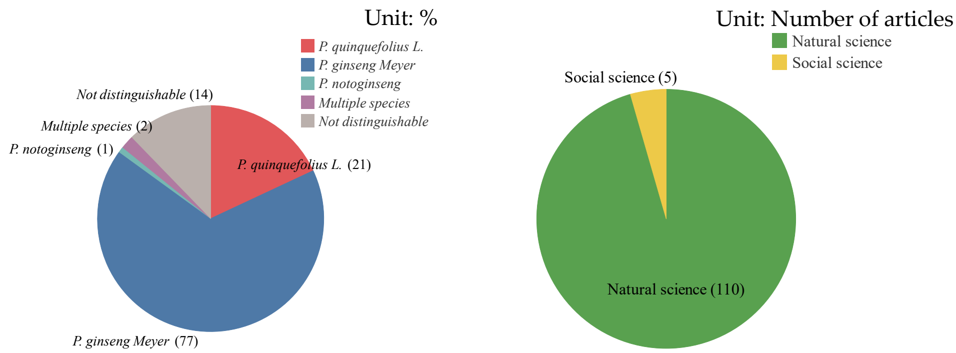


Figure 3. Distribution of wild-simulated ginseng articles by country and year (N = 115). The numbers indicate total articles published from January to December. However, the number of articles in 2020 includes articles from January 2020 to October 2020. The category of multiple countries means more than one country and the category of unspecified means no specific country.

Regarding WSG species, more than 65% of the selected articles investigated *P. ginseng Meyer*, followed by *P. quinquefolius* L. (18%) and *P. notoginseng* (1%) (Figure 4a). Only 5% of the publications belonged to the field of social science, whereas 95% of them belonged to the field of natural science (Figure 4b). The results indicate a lack of social science approach in WSG studies. Most WSG publications are based on the natural science approach and methodology for examining the components of WSG and their medicinal effects. Only a total of five studies applied social science aspects to WSG studies (Figure 4b). Burkhart et al. [67] conducted mixed-method studies on the perspective of stakeholders on federal government conservation efforts such as Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and they concluded that the top-down regulatory approach has limitations on conserving WSG in Pennsylvania [67]. McGraw et al. [35] reviewed scientific findings to understand how environmental changes and direct and indirect interactions with humans affect WSG in North America [35]. Schmidt et al. [68] applied geoadditive regression models to investigate the joint effects of environmental and social factors on ginseng harvest in the USA. The study reports that an overexploitation of WSG violates federal regulation, and a high correlation exists between harvesting and poverty [68]. Chamberlain et al. [69] examined the sociocultural, economic, and ecological elements of sustainable management of NTFPs, and they analyzed many medicinal species in the USA, including WSG. The review concluded that much more research and development is needed to ensure the long-term sustainability of NTFPs, their cultural values, and recognition of economic potential [69]. Jiang and Tian [70] investigated the saponin content in forests using high-performance liquid chromatography (HPLC), and they found that the saponin content of ginseng from Chinese forests is significantly different, suggesting policy support such as investment and optimization of marketing models to promote them [70].



(**a**) Wild-simulated ginseng species (**b**) Wild-simulated ginseng study fields

Figure 4. Distribution of wild-simulated species (**a**) and study fields (**b**) (*N* = 115).

5.2. Characteristics of Wild-Simulated Ginseng Research

The research analyzed WSG study areas by classifying them into four categories, namely growth conditions, components, effects on the environment, and effects on animals/humans. In the growth conditions category, site conditions (19) have been mostly studied, followed by growth (8), microstructure (7), genetic diversity (6), and photosynthesis (4) (Figure 5a). Among WSG components, most WSG articles covered ginsenoside (26), genome (7), and phenolic compounds (3) (Figure 5b). Regarding the effects of WSG, anti-oxidation (11) and anti-cancer (5) effects have been mostly examined. Most of the anti-oxidant and anti-cancer studies were related to ginsenoside. Lastly, biodiversity (5) was the hottest topic in the environmental effects of WSG (Figure 5c,d).

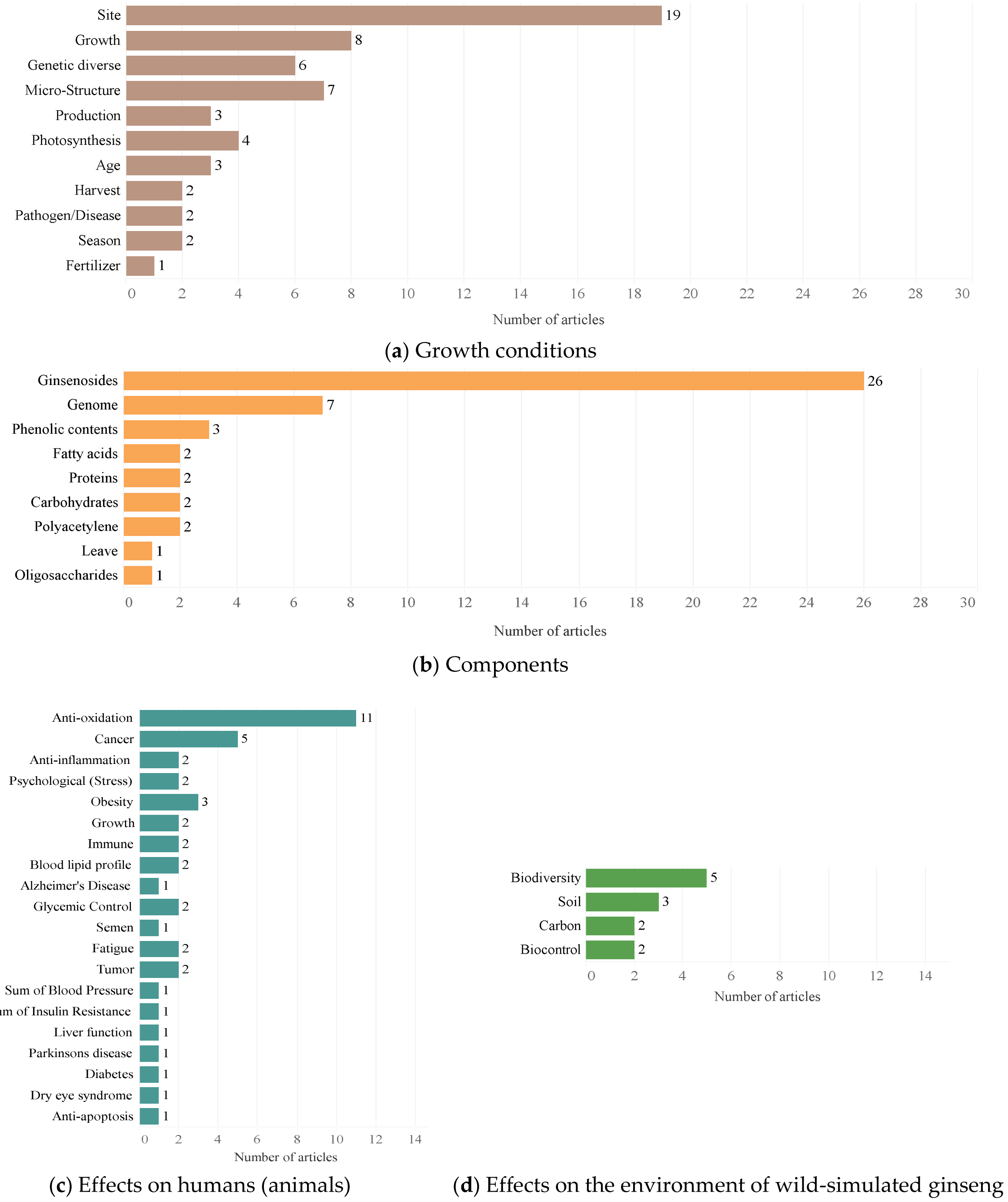


Figure 5. Characteristics of WSG research: (**a**) growth conditions, (**b**) components, (**c**) effects on humans (animals), and (**d**) effects on the environment of wild-simulated ginseng.

5.3. Keyword Frequency

Table 2 shows the frequency of the top 25 keywords out of a total of 481 keywords from the 115 selected articles. The top keywords are mostly ginseng types or species, such as Asian ginseng species, *P. ginseng* (49). As 11 anti-oxidation studies have been conducted (Figure 5c), the relevant keyword, antioxidant activity, was designated with the fifth-highest keyword frequency. However, since frequency analysis alone has limits to discovering the relationship between semantic structures and context of WSG research, it is necessary to look at the knowledge structure of the study through topic modelling analysis.

Table 2. Frequency of the top 25 keywords.

Rank	Keywords	Frequency
1	*Panax ginseng*	49
2	wild-simulated ginseng	30
3	ginsenoside	25
4	ginseng	16
5	antioxidant activity	10
6	wild ginseng	10
7	cultivated ginseng	9
8	metabolite	8
9	American ginseng	7
10	genetic diversity	7
11	cytotoxicity	5
12	HPLC	5
13	medicinal plant	5
14	plant conservation	5
15	UPLC-Q-TOF-MS	5
16	soil	4
17	Araliaceae	3
18	bacterial endophyte	3
19	*Burkholderia stabilis*	3
20	climate change	3
21	ginseng pathogens	3
22	harvest	3
23	identification	3
24	pharmacopuncture	3
25	saponin	3

5.4. Topic Analysis

As a result of topic modelling, five topics (Table 3) were derived from the large keyword network (Figure 6). The five topics included 336 keywords, excluding keywords with high TF-IDF scores as mentioned in the method Section 4.4 Topic Modelling. Table 3 displays the ranks of keywords according to the topic. Each topic was named depending on the characteristics of extracted keywords. Topic A was named "Medicinal effects", and it included keywords on the medical and pharmacological functions of WSG, such as medicinal plant, insulin, Chinese medicine, Tuina, and chronic fatigue syndrome. The studies related to Topic A indicate the wide use of WSG for various medicinal purposes, and they investigated methodologies to maintain or enhance the medicinal efficacy of WSG [71,72]. Furthermore, the remedial effects of WSG have been detected focusing on polyacetylene compounds, and many studies have compared WSG with other medicinal herbs [8,73]. Topic B was named "Metabolite analysis", including relevant keywords such as ultra-performance liquid chromatography–tandem mass spectrometry (UPLC-Q-TOF-MS), HPLC, bioreactor culture, discrimination model, quantitative analysis, orthogonal partial least squared-discriminant analysis (OPLS-DA), and vacuum freeze-drying. These keywords are related to the identification and quantification of WSG ingredients. HPLC, UPLC-Q-TOF-MS, and OPLS-DA are analytical techniques and methods to separate, identify, and quantify each component of WSG [74]. OPLS-DA, in particular, was used as a statistical technique to find the differences in components between different experimental groups by maximizing data visualization of metabolites in WSG [75]. Topic C was "Genetic diversity", which consisted of keywords such as genetic diversity, RAPD, 16S rDNA, UPGMA, genetic differentiation, Illumina MiSeq sequencing, and transcriptome. The terms cell, gene, and microunits belonged to Topic C. Various attempts have been made to identify genetic diversity across a wide variety of WSG species [76–78]. Particularly, keywords shown in Topic C (Table 3), such as RAPD, ISSR, and de novo RNA sequencing, are related to gene sequencing. Topic D was named "Cultivation conditions", which comprises keywords such as plant conservation, harvest, climate change, understory ginseng, photosynthesis, NTFPs, restoration ecology, endangered species, suitable ecological area, forest farming, winter warming, frost, and demography. Topic D focused on growth, cultivation, and cultivation environment. The demand for forest products is increasing worldwide [79], and the harvest pressure on ginseng is also increasing [68]. Along with the increase in the demand for WSG, several studies have investigated the environmental variables to predict the probability of ginseng growth using a species distribution model [68]. Furthermore, studies have been conducted on the ecology and conservation of WSG. Direct and indirect interacting threats, such as deer browsing, harvest, and climate change, and the long-term persistence of WSG have been examined based on the ecological and cultivation characteristics of WSG [35]. Lastly, Topic E was "Bioactive compounds", which included various bioactive compounds directly or indirectly related to WSG. Figure 7 indicates the structure of Topic E with three sub-clusters of bioactive compounds. The first sub-cluster contains keywords related to antimicrobial compounds such as ginseng pathogens, *Burkholderia stabilis*, bacterial endophyte, and biocontrol. *B. stabilis* is a bacterial endophyte isolated from WSG. *B. stabilis* EB159 is used as a biocontrol agent against ginseng pathogens [71]. The second sub-cluster includes the keywords related to brain health compounds such as prefrontal cortex, schizophrenia, and phencyclidine. The third sub-cluster includes the keywords related to antioxidant compounds such as DPPH radicals, kaempferol, and quercetin. Quercetin and kaempferol are the antioxidant compounds found in wild ginseng leaves [80].

Table 3. Five topic groups related to wild-simulated ginseng.

Topic A	**Topic B**	**Topic C**	**Topic D**	**Topic E**
Medicinal Effects	**Metabolite Analysis**	**Genetic Diversity**	**Cultivation Conditions**	**Bioactive Compounds**
medicinal plant	metabolite	cultivated ginseng	American ginseng	ginseng pathogens
cytotoxicity	UPLC-Q-TOF-MS	genetic diversity	plant conservation	*Burkholderia stabilis*
understory ginseng	HPLC	soil	Harvest	bacterial endophyte
fermentation	cultivated ginseng	cytotoxicity	climate change	quercetin
photosynthesis	saponin	leaf litter	medicinal plant	kaempferol
Korea	identification	RAPD	Araliaceae	metabolite
edible plants	phenolic compounds	pharmacopuncture	genetic diversity	bisphenol A
polyacetylene	bioreactor culture	transcriptome	trimethyltin	testicular toxicity
Allium tricoccum	adventitious roots	suitable site	IL-6	ethyl acetate extract
forest inventory	microorganism	calcium oxalate crystal accumulation	geoadditive model	biocontrol
Actaea racemosa	Araliaceae	soil microbial community	open access resource	DPPH radicals
local and traditional ecological knowledge	cultivation age	16s rDNA	forest herbaceous plant	ginseng leaves
panaxidol	discrimination model	inter-simple sequence repeat (ISSR)	timeseries	genome sequence
forestry economy	genomic	China	species distribution model	cell free supernatant
development countermeasures	subcritical water	genetic differentiation	life table response experiment	leaf
ovarian cancer cells	discrimination	terpenoids biosynthesis genes	non timber forest products	biological control
ginseng extracts	quantitative analysis	terpenoid phytohormones	restoration ecology	insulin
Bifidobacterium	shikonins	mulch	endangered species	panaxidol
growth	gamma irradiation	plant density	Jackknife test	complementary and alternative medicine
stomatal conductance	camptothecin	UPGMA	ecological suitable area	pharmacopuncture
age	biomass	population	deer browsing	medicinal plant

Table 3. *Cont.*

Topic A	Topic B	Topic C	Topic D	Topic E
Medicinal Effects	**Metabolite Analysis**	**Genetic Diversity**	**Cultivation Conditions**	**Bioactive Compounds**
insulin	OPLS-DA	Illumina MiSeq sequencing	extinction vortex	apoptosis
Chinese medicine	vacuum freeze drying	biomarker fungal	plant husbandry	polyacetylene
genome divergence	cell suspension	complementary and alternative medicine	forest farming	Korea
FISH	Chinese medicine	*de novo* RNA sequencing	woods grown American ginseng	photosynthesis
rRNA gene	peptide	microsatellites	cultivated American ginseng	productivity
Tuina	peptidomics	heterozygosity	winter warming	livestock
GISH	ginseng growth cycle	gene expression	frost	antibiotic
chronic fatigue syndrome	EC	Ultra-performance liquid chromatography-tandem mass spectrometry	demography	alternative
massage	agroforestry systems	Chinese medicine	testicular toxicity	hepatocellular carcinoma

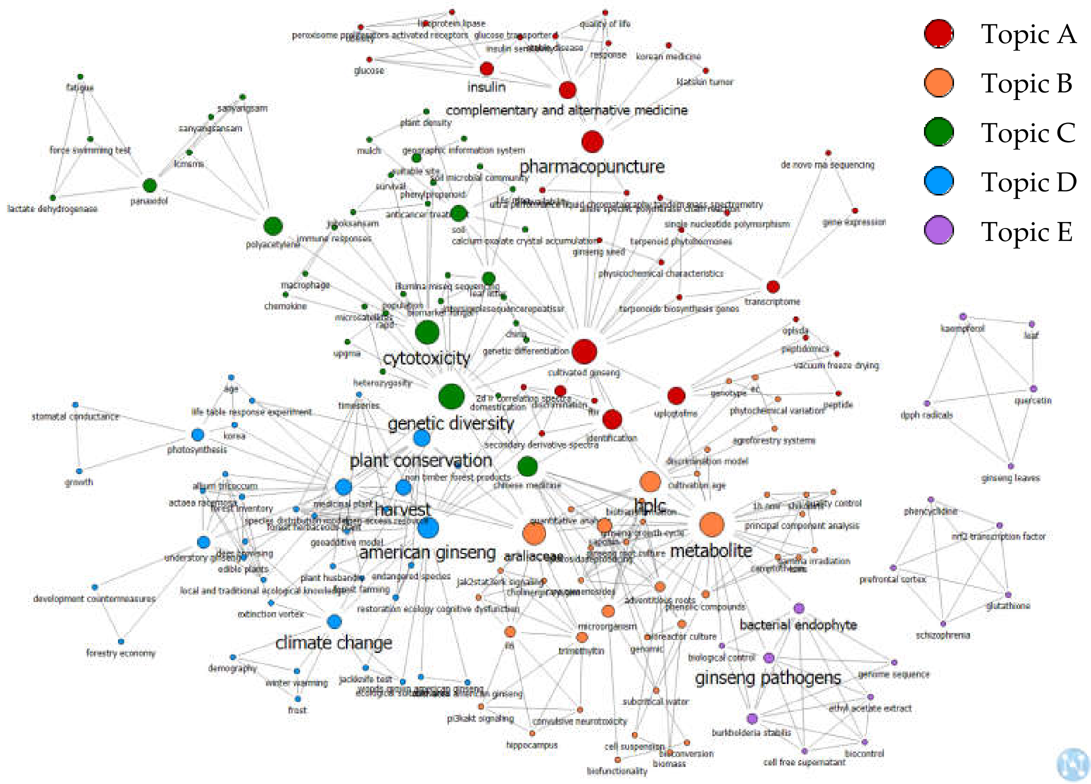


Figure 6. Clustering of topics related to wild-simulated ginseng. The five resulting clusters are colored by topic group. The size of the nodes is proportional to the sum of the links, called centralities. The bigger the size of the node is, the more influential the node is in the network. Topic A: Medicinal effects; Topic B: Metabolite analysis; Topic C: Genetic diversity; Topic D: Cultivation conditions; Topic E: Bioactive compounds.

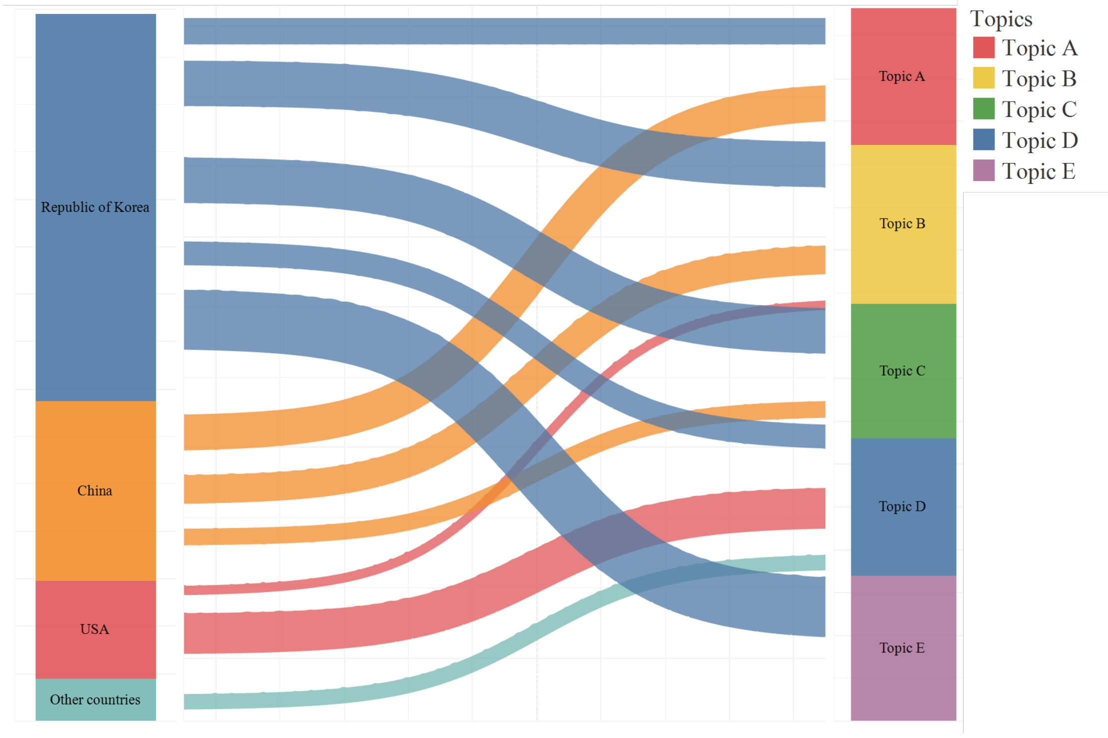


Figure 7. Sankey diagram on topics of wild-simulated ginseng research. The flow diagram shows the country names on the left and aggregation into the five topics on the right. The dimension of rectangles on the right is proportional to the fields' prevalence. Colors are the same as in Figure 2. Topic A: Medicinal effects; Topic B: Metabolite analysis; Topic C: Genetic diversity; Topic D: Cultivation conditions; Topic E: Bioactive compounds.

6. Discussion

6.1. Studies on Wild-Simulated Ginseng by Country

The overall aggregation and examination of topics by country were analyzed (Figure 7). Keywords from WSG articles published for approximately 40 years, including no publication in 11 years from 1989 to 1999, were evenly distributed into five topics, namely Topic A (19.05%), Topic B (22.02%), Topic C (19.64%), Topic D (19.05%), and Topic E (20.24%).

Studies on WSG were mainly conducted in three countries, namely the Republic of Korea, China, and the USA (Figure 2). WSG studies in the Republic of Korea were evenly distributed into all topics, but studies from China and the USA were conducted on some dominant topics. Chinese researchers have focused more on Topic A, "Medicinal effects", but less on Topic D, "Cultivation conditions". On the other hand, the USA shows an opposite pattern, with more studies on Topic D, "Cultivation conditions".

The Republic of Korea conducted the most number of studies on WSG based on a long history of WSG cultivation, since many studies have evaluated the therapeutic potency and cultivation technology of WSG since the first century [29]. Studies on Topic A (medicinal effects) in the Republic of Korea mainly focused on traditional medicinal remedies, including complementary and alternative medicine, such as pharmacopuncture. These studies evaluated the effects of WSG on patients with klatskin tumor [81], cancer [48], and obesity [7]. Topic B (Metabolite analysis) papers were related to the antioxidant effects of ginseng by analyzing the bioprocessing of saponins [82]. Few studies have reviewed microbial ginsenosides that can be used as special additives in the food and medicinal industry [83]. Several papers examined the genetic diversity (Topic C) of WSG populations. Specifically, the studies evaluated genetic differences [84], functional compounds [73], and genetic relationships among different types of cultivated ginseng [78]. Few studies have investigated the cultivation conditions (Topic D), and they indicate significant values of effective environments for ginseng growth, such as shade, soil, photosynthesis [85], mountain conditions [86], and forest types [87]. Lastly, most papers from the Republic of Korea included keywords on bioactive compounds (Topic E). The efficacy of WSG on the health of both humans and livestock has been highlighted through experiments. For instance, researchers found that WSG can be used as a potential biocontrol agent against some chemicals [71], and it possesses an ability to protect hormones for anti-apoptosis [28,88].

Next, the second-largest number of WSG studies was conducted in China (Figure 3). Publications on WSG in China were mainly related to "Medicinal effects" (Topic A) and "Metabolite analysis" (Topic B). The Chinese have been consuming ginseng since thousands of years as a traditional herbal medicine due to its medicinal effects [76,89]. Due its high medicinal value (Topic A), ginseng has been cultivated in large areas in China. Many studies have been conducted on its medicinal basis and application [90,91]. Based on advanced research on the noteworthy medicinal effects of ginseng, such as modulation of immune functions and metabolic processes, anti-stress activity, and improvement of the memory process, various preparations of ginseng have been approved through metabolite analysis (Topic B) for clinical application in China [91].

Lastly, the research on WSG in the USA is shown in Figure 7. A number of studies have been conducted on "Cultivation conditions", classified as Topic D. For nearly 300 years, American ginseng has been harvested in large quantities in eastern and central North America, and it has been exported to China [18,92]. In 1975, however, American ginseng was listed in the CITES Appendix II [35,93]. All species listed in Appendix II are considered susceptible to extinction without trade control, and in the case of American ginseng, there were concerns about existing high yields [35]. Since American ginseng was listed in Appendix II of CITES, early research on the growth and ecology of ginseng population was promoted, which can be explained as an opportunity to support many studies on WSG cultivation environment in the USA [32,94,95]. Moreover, in recent years, American ginseng has been recommended as a candidate for agroforestry crops that can receive premium prices through forest farming practices, especially the "wild-simulated" approach [18]. The production of WSG provides an economic benefit for forest landowners for generating short-term income. Several studies have identified a suitable environment for cultivating WSG [18,92].

6.2. Changing Topic Trends of Wild-Simulated Ginseng Studies

This study analyzed the changing trends in the share of topics over time by categorizing the results over five-year-periods (Figure 8). Before 2005 (Period 1), Topic E, "Bioactive compounds", was the least studied topic (11.76%), and other topics had a similar share. In Period 2, however, Topic A, "Medicinal effects", was prominent (30.95%) and Topic C, "Genetic diversity", also received more attention with an increase of more than 6%. However, studies on Topic B, "Metabolite analysis", decreased significantly (9.52%). In Period 3, the proportion of studies on "Cultivation conditions", Topic D, increased by 10% (31.71%). On the other hand, the proportion of studies dealing with Topic A, "Medicinal effects", decreased from 30.95% (Period 2) to 13.41% (Period 3). Recently, Topic E, "Bioactive compounds", became the most prominent research area in Period 4 (24.72%), but the proportion of studies on Topic D declined. A decrease in the ratio of topic groups does not indicate a decrease in the number of keywords. Both the number of articles and keywords on WSG increased over time (Figures 3 and 8). Figure 8 shows changes in the relatively dominant topics of keywords along with the ratio values.

We observed that in the beginning of WSG research, researchers were interested in the medicinal effects, metabolite analysis, genetic diversity, and cultivation conditions of WSG. However, significant differences were observed in Periods 2 and 3. In Period 2, most studies were conducted on "Medicinal effects", and in Period 3, most studies were conducted on "cultivation conditions" (more than 30%). In Period 4, the study focus changed to "metabolite analysis" and "bioactive compounds". The percentage and weight of the five topics changed in every period. Interestingly, the ratio of studies on bioactive compounds increased continuously while trends of other topics changed in an irregular pattern over time. The change in the ratio of dominant research topics from medicinal effects and cultivation conditions to metabolite analysis and bioactive compounds indicates a shift in research trends from biological and ecological to bioactive metabolite evaluation of WSG. The former includes biological growth, suitable cultivation, and medicinal components of WSG. It concentrates on the interaction between WSG and their cultivation environment. The latter includes identifying the functions of WSG components. Some studies have conducted a detailed analysis of WSG components, including the examination of single compounds of WSG such as kaempferol and quercetin. This approach is deeply related to the application of WSG in treating human diseases. It offers evidence of the contribution of WSG to enhance human health. The evidence is closely linked with value addition [82] in the utilization of WSG. As the global interests in ginseng consumption increase in the market of health foods [94,96], this trend highlights a hidden potential for the expansion of the industrial market of WSG with a focus on bioactive metabolite traits for human wellbeing.

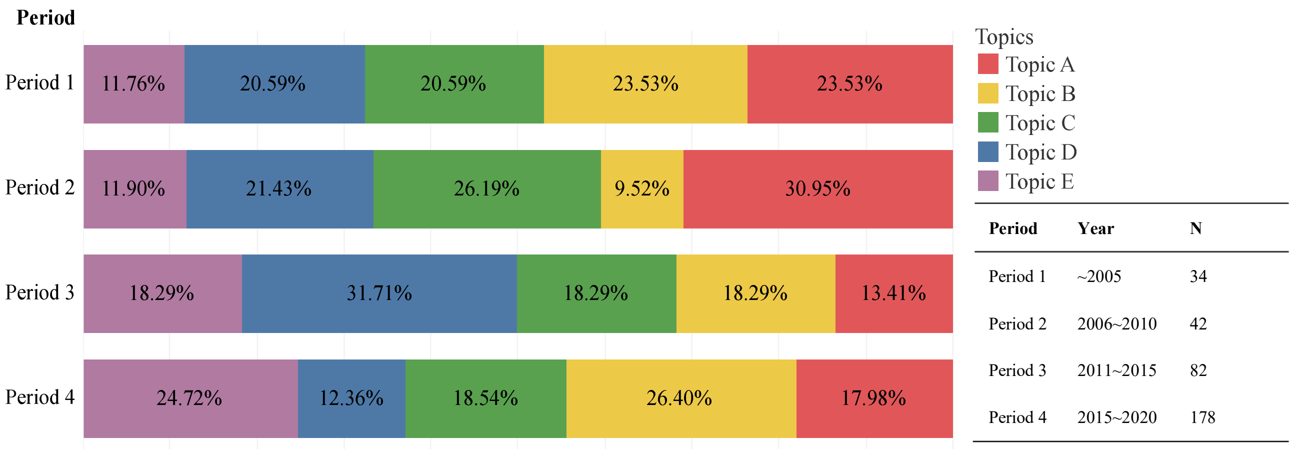


Figure 8. Change in topic share by period. Topic A: Medicinal effects; Topic B: Metabolite analysis; Topic C: Genetic diversity; Topic D: Cultivation conditions; Topic E: Bioactive compounds.

7. Conclusions

This study explored WSG research trends using systematic review and topic modelling. The systematic review approach allowed us to examine the existing literature thoroughly with an obvious, repeatable, and minimal bias process to search, identify, select, evaluate, and aggregate research evidence. Topic modelling allows us to analyze what topics have been conducted and how the topic has changed recently. We found that WSG studies mostly targeted ginsenoside (Figure 5b) and its effects on humans/animals (Figure 5c), the top keywords were related to anti-oxidation (Table 2), and research trends varied by country (Figure 7) and time period (Figure 8). Moreover, the research focus changed from the biological properties of WSG and its cultivation conditions to the precise identification and characterization of the bioactive metabolites of WSG. This change indicates an increased academic interest in the value-added utilization of WSG.

Considering the findings of this study, some suggestions are recommended for future studies on WSG. First, future studies need to consider diverse approaches. Most studies on WSG examined the effects of WSG in natural science (Figures 4b and 5c). For understanding and supporting the WSG industry and market, more studies should be conducted with a social science approach, including value chain analysis, household survey, consumer preference, and trade policy. Additionally, a meta-analysis is necessary to statistically analyze the collected data according to subjects, as our results provided specific subject categories (Figure 5c,d). Meta-analysis combines individual findings into a large study and then proves them statistically. Meta-analysis, starting from anti-oxidant, -cancer, and

-obesity studies, with a relatively sufficient sample size and more data can precisely analyze the trends. Theoretically, only two or three studies are sufficient to conduct a meta-analysis; however, understanding the statistical power of meta-analysis is most important [95].

Although this systematic approach identified the important keywords and research trends, this study had some limitations. First, our study showed a global trend using only English-written papers due to language barriers, although the Republic of Korea and China (Figure 2) are the two major countries. For a more comprehensive study, future research needs to include WSG research papers written in local languages. Moreover, morpheme analysis determines the quality of the analysis in topical modelling analysis. To overcome the disadvantages of unsupervised learning of LDA techniques and to enhance the appropriateness of topics, future studies should apply various transformed techniques and compare the results using new methodologies, such as supervised LDA, extended to conduct supervised learning, and hierarchical LDA, extended to allow multiple layers of the subject structure. Despite these limitations, the study offered dominant research keywords and topic categories of WSG studies. These results will contribute to understanding the trend of WSG research and designing future research on WSG.

Author Contributions: Conceptualization, S.S. and M.S.P.; methodology, S.S. and M.S.P.; software, S.S.; formal analysis, S.S., M.S.P., H.L. (Hansol Lee), H.L. (Haeun Lee), S.L., T.H.K., and H.J.K.; data curation, S.S.; writing—original draft preparation, S.S., H.L., H.L., S.L., and T.H.K.; writing—review and editing, M.S.P. and H.J.K.; visualization, S.S.; supervision, M.S.P.; project administration, M.S.P.; funding acquisition, M.S.P. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Creative-Pioneering Researchers Program through Seoul National University (SNU).

Informed Consent Statement: Not applicable.

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

Appendix A

Table 1. Search Query.

Database	Search Query
SCOPUS	TITLE-ABS-KEY (“wild ginseng” OR “wild American ginseng” OR “wild panax ginseng” OR “wild Asian ginseng” OR “wild Asiatic ginseng” OR “wild Chinese ginseng” OR “wild Korean ginseng” OR “wild oriental ginseng” OR “forest ginseng” OR “forest American ginseng” OR “forest panax ginseng” OR “forest Asian ginseng” OR “forest Asiatic ginseng” OR “forest Chinese ginseng” OR “forest Korean ginseng” OR “forest oriental ginseng” OR “wild-simulated ginseng” OR “mountain cultivated ginseng” OR “forest cultivated ginseng” OR “wild-simulated ginseng” OR “wood cultivated ginseng”)
Web of Science	TS (“wild ginseng” OR “wild American ginseng” OR “wild panax ginseng” OR “wild Asian ginseng” OR “wild Asiatic ginseng” OR “wild Chinese ginseng” OR “wild Korean ginseng” OR “wild oriental ginseng” OR “forest ginseng” OR “forest American ginseng” OR “forest panax ginseng” OR “forest Asian ginseng” OR “forest Asiatic ginseng” OR “forest Chinese ginseng” OR “forest Korean ginseng” OR “forest oriental ginseng” OR “wild-simulated ginseng” OR “mountain cultivated ginseng” OR “forest cultivated ginseng” OR “wild-simulated ginseng” OR “wood cultivated ginseng”)

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