

Rhodiola rosea: A Quantitative and Qualitative Assessment of Global Publications Output during 2003-18

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ABSTRACT

A quantitative and qualitative assessment of global research output (2016) on the "*Rhodiola rosea*" plant based on select bibliometric indicators, using Scopus database covering period 1993-2018, is presented here. Analyzed data on a series of bibliometric measures, like average annual growth, citations per paper, international collaborative papers, relative citation index, activity index, top productive countries, organizations, authors, journals and highly cited papers. The global publications registered an annual average growth rate of 12.97% and its citation impact averaged to 17.59 citations per paper. China and USA together account for more than 36% share of global output on *Rhodiola rosea*, whereas other 8 top ranking countries accounted each for global share between 4.06% and 7.60% during 2003-18. 83.04% global publication share and 89.95% global citation share has been contributed by top 10 countries during 2003-18. Sweden (2.78), Canada (1.17) and USA (1.11) registered the highest relative citation index among top 10 countries during 2003-18. Swedish Herbal Institute, Askloster, Sweden (21 papers), Medical University of Warsaw,

Poland (14 papers), Corvinus University of Budapest, Hungary were the three the most productive organizations and Z. Gyorgy and A. Panossian (18 papers each) and G. Wikman (14 papers) were the three top most productive authors. Phytomedicine (25 papers), Phytotherapy Research (21 papers) and Evidence-based Complementary and Alternate Medicine (15 papers) were the three leading journals contributing research in this area.

Key words: *Rhodiola rosea*, Medicinal plants, Global publications, Citations, International collaborative papers, Bibliometrics, Scientometrics.

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INTRODUCTION

Rhodiola rosea, is a botanical name of Roseroot crop (also called golden root, Arctic root, rose root, Rosavin, *Rhidola*, Aaron's rod, *Rhidiola rhizome* and solo). It grows primarily in dry sandy ground in cold and mountain regions of the world, including much of the Arctic, the mountains of Central Asia, scattered in eastern North America and parts of Europe. It grows on sea cliffs and on mountains at high altitude. It belongs to the stonecrop family named *Crassulaceae*, sub family of *Sedoideae* and genus *Rhodiola*. It is a perennial and fleshy succulent plant, which grows up to around 30 cm.^{1,2}

Typical uses of *Rhodiola rosea* are many. An extract of the root is used in cosmetic preparations as an antioxidant, astringent and skin conditioner. The dried root smells strongly of roses. They may be used to distill rose-water. The leaves and shoots are eaten raw or cooked like spinach and are sometimes added to salads. The plant is also grown as an ornamental, where it can be used as a ground cover. The roots of *Rhodiola rosea* are used as medicine.³

For centuries, *Rhodiola rosea* has been used in the traditional medicine of Russia, Scandinavia and other countries. Its use was first recorded by the Greek physician Dioscorides in 77 CE in *De Materia Medica*. It has been used for centuries as a traditional medicine in Russia, Scandinavia and other countries for the treatment of fatigue, depression, anemia, impotence, GI ailments, infections and nervous system disorders and to promote physical endurance, longevity and work productivity. *Rhodiola* appeared in the scientific literature of Sweden, Norway, France, Germany, the Soviet Union and Iceland as early as 1725. *Rhodiola rosea* has been

an accepted medicine in Russia since 1969 for the treatment of fatigue, somatic and infectious illness, psychiatric and neurologic conditions and as a psychostimulant to increase memory, attention span and productivity in healthy individuals. It is also officially registered in Sweden and Denmark and is widely used in Scandinavia as a general tonic and to increase mental work ability under stress.⁴

About 140 chemical compounds are in the subterranean portions of *Rhodiola rosea*. It is classified as an adaptogen. It contains a range of antioxidant compounds and its adaptogenic activities are attributed to its unique phenylpropanoids rosavin, rosarin and rosindirin and to phenyl-ethanol derivatives p-tyrosyl and salidroside (also called rhodiolide), as well as to flavonoids, triterpenes, monoterpenes and phenolic acids. Rosavins are the accepted marker compounds for water and alcohol extracts.^{1,4}

The current medical and pharmacological texts describe its use as a stimulant good for fatigue, for somatic and infectious illnesses, in psychiatric and neurological conditions and in healthy individuals to relieve from fatigue and to increase attention span, memory and work productivity. *Rhodiola rosea* enhances learning and memory in animal models and increase 5-HT levels in the frontal cerebral cortex, promotes release of catecholamines that activate the cerebral cortex and the limbic system. *Rhodiola rosea* may prevent or ameliorate some age-related neurological dysfunctions.^{5,6}

Research both from animal models and human clinical trials indicates a number of favorable effects associated with its use, including CNS

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stimulation, pronounced anti-stress effects, enhanced physical work and exercise performance, increased muscle strength, reduction in mental fatigue and prevention of high altitude sickness. Cardioprotective and anticancer effects also have been attributed to its intake. *Rhodiola rosea* extract exhibited an anti-inflammatory effect and protected muscle tissue during exercise. Studies have demonstrated its ability to induce a general sense of well-being and reduce situational anxiety. It has demonstrated improvement in depressive syndromes, mental and physical fatigues secondary to medical conditions, sexual dysfunction, thyroid hypofunction (without causing hyperthyroidism), thymus gland functioning, adrenal functioning and menopause-related conditions. Its mechanism of action is partly attributed to the herb's ability to influence levels of monoamines, including serotonin, dopamine and norepinephrine in the cerebral cortex, brainstem and hypothalamus through inhibition of degradation enzymes and facilitation of neurotransmitter support in the brain. It also appears to prevent catecholamine release and camp elevation in the myocardium, to prevent depletion of adrenal catecholamines by acute stress and to induce opioid peptide biosynthesis and activation of central and peripheral opioid receptors. Enhanced antitumor and antimetastatic activity has been demonstrated when *Rhodiola rosea* extract is combined with cyclophosphamide (an antitumor agent).⁷ The rose root imparts normalizing influences on adverse physical, chemical and biological disturbances but is otherwise innocuous. In India, the plant has been growing wild in the high altitudes of the Himalayas and known as solo. The Defence Research and Development Organization organization Defence Institute of High Altitude Research in India has taken on the responsibilities of its conservation, as well as the development of multiple management practices and the development of health foods, supplements and nutraceuticals with an aim of exploring and putting to good use, the limited flora and vegetation found in this cold arid zone. Considering the hilly terrains and a difficult lifestyle with significantly low levels of atmospheric oxygen, nutritive foods for sustenance of energy are an absolute must in the mountains, *Rhodiola rosea* has been shown to possess properties of mitigating the harmful gamma radiations, which are typically released during warfare. A certain phytochemical from this plant has been used in the management of high-altitude sickness. For a hilly terrain like Ladakh and Leh, where neuro-protection and biological tissue regeneration are always desirable, this particular species of *Rhodiola* may prove to be very beneficial.⁸

No scientometric study had been carried out in the past on *Rhodiola rosea* plant. However, few other research studies are available, which quantitatively and qualitatively analyze global and Indian literature on individual medicinal plants, including on *Aloe vera*,⁹ *Azadirachta indica*,¹⁰ *Curcuma longa*,¹¹ *Glycyrrhiza glabra*,¹² *Nigella sativa*,¹³ *Ocimum santum*,¹⁴ *Phyllanthus emblica*,¹⁵ *Tinospora cordifolia*¹⁶ and *Withania somnifera*.¹⁷

The present study analyses the performance of global research on *Rhodiola rosea* plant, based on publications output indexed in Scopus database during 1993-2018. In particular, it studied the distribution of global publication output of the world and of 10 most productive countries, by document type and source type, growth rate of its annual and cumulative output, the share of international collaborative publications, broad subject-wise scatter across sub-fields, identification of significant keywords depicting trends in research, publication output and share and citation impact of its top 15 global organizations, authors and journals, identification of leading journals and characteristics of its high cited publications.

METHODS

Rhodiola rosea plant publications for the present study was derived from the Scopus database (<http://www.scopus.com>) covering the period 2003-

18. Keywords, such as "*Rhodiola rosea*" was searched in "Keyword" and "Title of Paper" tags during the period 2003-18 to get publication data on global output on *Rhodiola rosea* plant (566 records) during this period. For specific information on global publication data on "*Rhodiola rosea*", this search string was further restricted to individual country by name in "country tag" one by one to ascertain publication output of top 10 most productive countries (including India). The search string was subsequently refined, using analytical tags in Scopus database, by "subject area tag", "country tag", "source title tag", "journal title name" and "affiliation tag", to get data/information on the distribution of publications output by subject, collaborating countries, author-wise, organization-wise and journal-wise, etc. For citation data, citations to publications were also collected from date of publication till 20 August 2019.

(KEY ("*Rhodiola rosea*") OR TITLE ("*Rhodiola rosea*")) AND PUB-YEAR > 2002 AND PUBYEAR < 2019

ANALYSIS

Rhodiola rosea global research publication output cumulated to 566 publications during 2003-18. Its annual publications increased from 14 in the year 2003 to 47 in the year 2018, registering 12.97% growth per annum. The maximum research output (50) was in the year 2012 and minimum (14) in the year 2003. The cumulative publication output of *Rhodiola rosea* increased from 211 in 8 years (2003-10) to 355 publications during succeeding eight-year period 2011-18, registering 68.25% growth. The global publications citation impact of *Rhodiola rosea* plant averaged to 17.59 Citations Per Publication (CPP) during 2003-18; its eight-yearly citation impact, however, averaged to 29.57 CPP for the period 2003-10, which sharply declined to 10.46 CPP for the period 2011-18 (Table 1). Of the total global publications output, 77.21 (437) appeared as articles, 14.84% (84) as reviews, 1.94% (11) as notes, 1.59%

Table 1: *Rhodiola rosea* Plant Annual Publications during 2003-18.

Publication Period	World		
	TP	TC	CPP
2003	14	451	32.21
2004	16	470	29.38
2005	15	570	38.00
2006	21	598	28.48
2007	25	688	27.52
2008	31	707	22.81
2009	55	1758	31.96
2010	34	997	29.32
2011	38	767	20.18
2012	50	977	19.54
2013	58	714	12.31
2014	44	386	8.77
2015	30	341	11.37
2016	48	286	5.96
2017	40	179	4.48
2018	47	65	1.38
2003-11	211	6239	29.57
2012-18	355	3715	10.46
2003-18	566	9954	17.59

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper

Table 2: Global Publication Output and Share of Top 10 Countries on *Rhodiola rosea* during 2003-18.

S.No	Name of the Country	Number of Papers			Share of Papers			TC	CPP	ICP	%ICP	RCI
		2003-10	2011-18	2003-18	2003-10	2011-18	2003-18					
1	China	28	93	121	13.27	26.20	21.38	1908	15.77	18	14.88	0.90
2	USA	27	57	84	12.80	16.06	14.84	1644	19.57	43	51.19	1.11
3	Russia Federation	22	21	43	10.43	5.92	7.60	589	13.70	10	23.26	0.78
4	Italy	10	31	41	4.74	8.73	7.24	682	16.63	7	17.07	0.95
5	Germany	14	23	37	6.64	6.48	6.54	658	17.78	26	70.27	1.01
6	Sweden	18	16	34	8.53	4.51	6.01	1663	48.91	21	61.76	2.78
7	Poland	15	18	33	7.11	5.07	5.83	462	14.00	9	27.27	0.80
8	Canada	13	17	30	6.16	4.79	5.30	618	20.60	12	40.00	1.17
9	Taiwan	5	19	24	2.37	5.35	4.24	327	13.63	5	20.83	0.77
10	U.K.	2	21	23	0.95	5.92	4.06	403	17.52	15	65.22	1.00
	Total	154	316	470	72.99	89.01	83.04	8954	19.05	166	35.32	1.08
	World	211	355	566				9954	17.59			
	Share of 10 Countries in World Total	72.99	89.01	83.04				89.95				

(9) as conference papers, 1.41% (8) as editorials, 1.06% (6) each as short surveys and erratum, 0.71% (4) as book chapters and 0.18% (1) as letter.

Leading Countries Research Output on *Rhodiola rosea*

The *Rhodiola rosea* research output had originated from 58 countries during 2003-18, of which, 32 published 1-5 papers each, 9 countries 6-10 papers each, 7 countries 11-20 papers each, 8 countries 21-50 papers each and 2 countries 84-121 papers. The top 10 most productive countries have contributed 23 to 121 publications each on *Rhodiola rosea* during 2003-18 (Table 2). The 10 leading countries on *Rhodiola rosea* research together accounted for 83.04% global publication share and 89.95% citation share during 2003-18; it however accounted for 72.99% global publication share during 2003-10 which increased to 89.01% during succeeding eight-year period 2011-18. Country-wise, the global publication share of 10 leading countries varied widely 5.92% to 26.20% during 2003-18, with China accounting for the highest publication share (21.38%), followed by USA (14.84%), Russia Federation, Italy, Germany and Sweden (6.01% to 7.60%) and other 4 countries from 4.06% to 5.83% during 2003-18. The global publications registered an increasing publication share in China, U.K., Italy, USA and Taiwan (from 2.98% to 12.93%), as against decrease in Germany, Canada, Poland, Sweden and Russian Federation (from 0.16% to 4.51%) in eight years period (2003-10 and 2011-18). Three of the 10 leading countries scored relative citation index above the world average of 1.08: Sweden (2.78), Canada (1.17) and USA (1.11) during 2003-18. India has comparatively contributed only 16 papers, ranked 14th in world output and registered citation per paper of 13.69, its performance in terms of relative citation index has below the world average (0.78).

International Collaboration

The international collaborative output of 10 leading countries on *Rhodiola rosea* research as a national share in the country-wise output varied widely from 14.78% (China) to 70.27% (Germany), with average share of 35.32% during 2003-18. Most surprisingly, India's international collaborative share in its national output in *Rhodiola rosea* research was comparatively small, 12.50%.

Subject-Wise Distribution of Research Output

According to the Scopus classification, the *Rhodiola rosea* global research output published during 2003-18 is distributed across seven sub-fields as per Scopus classification. The medicine accounted for the highest publications share (44.88%), followed by pharmacology, toxicology and pharmaceuticals (37.63%), biochemistry, genetics and molecular biology (32.69%), agricultural and biological sciences (21.02%), chemistry (12.72%), immunology and microbiology (6.18%) and neurosciences (4.77) during 2003-18. Its activity index, which computes change in research activity in the discipline over time 2003-10 to 2011-18 (world average activity index of a given subject is taken as 100), witnessed increase in biochemistry, genetics and molecular biology (from 97.15 to 101.69), agricultural and biological sciences (from 81.15 to 111.20), immunology and microbiology (from 84.31 to 109.33) and neurosciences (from 79.48 to 112.20), as against decline of research activity in medicine (from 102.44 to 98.55), pharmacology, toxicology and pharmaceuticals (from 103.27 to 98.06) and chemistry (from 115.49 to 90.79) from 2003-10 to 2011-18. Neuroscience, among various subjects registered the highest citations impact per paper of 32.52 CPP, followed by biochemistry, genetics and molecular Biology (22.16), pharmacology, toxicology and pharmaceuticals (21.22), chemistry (19.29), medicine (18.74), immunology and microbiology (13.29) and agricultural and biological sciences (10.84) during 2003-18 (Table 3).

Profile of Top 15 Most Productive Global Organizations

Two hundred forty-eight (248) organizations participated in global *Rhodiola rosea* research during 2003-18, of which 230 organizations contributed 1-5 papers each, 13 organizations 6-10 papers each and 5 organizations 11-21 papers each.

The productivity of top 15 most productive global organizations in *Rhodiola rosea* research varied from 5 to 21 publications and together they contributed 24.03% (136) global publication share and 36.32% (3615) global citation share during 2003-18. The scientometric profile of these top 15 organizations is presented in Table 4.

- **Six of these organizations** registered publications output greater than the group average of

Table 3: *Rhodiola rosea* Global Publications Distribution by Subjects during 2003-18.

S.No	Subject*	Number of Papers (TP)			Activity Index		TC	CPP	%TP
		2003-10	2011-18	2003-18	2003-10	2011-18			
1	Medicine	97	157	254	102.44	98.55	4759	18.74	44.88
2	Pharmacology, Toxicology and Pharmaceutics	82	131	213	103.27	98.06	4520	21.22	37.63
3	Biochemistry, Genetics and Molecular Biology	67	118	185	97.15	101.69	4100	22.16	32.69
4	Agricultural and Biological Sciences	36	83	119	81.15	111.20	1290	10.84	21.02
5	Chemistry	31	41	72	115.49	90.79	1389	19.29	12.72
6	Immunology and Microbiology	11	24	35	84.31	109.33	465	13.29	6.18
7	Neuroscience	8	19	27	79.48	112.20	878	32.52	4.77
	World Output	211	355	566	100.00	100.00	9954	17.59	

• There is overlapping of literature covered under various subjects
 TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper.

Table 4: Top 15 Most Productive Global Organizations: Cientometric Profile on *Rhodiola rosea* Research during 2003-18.

S. No	Name of the Organization	TP	TC	CPP	HI	ICP	%ICP	RCI
1	Swedish Herbal Institute, Askloster, Sweden	21	1503	71.57	18	17	80.95	4.07
2	Medical University of Warsaw, Poland	14	350	25.00	11	5	35.71	1.42
3	Corvinus University of Budapest, Hungary	11	58	5.27	5	7	63.64	0.30
4	University of Oulu, Finland	11	305	27.73	8	1	9.09	1.58
5	University of California, Irvine, USA	10	173	17.30	4	1	10.00	0.98
6	University of Camerino, Italy	10	320	32.00	9	1	10.00	1.82
7	Jiangnan University, China	9	297	33.00	6	0	0.00	1.88
8	University of Ottawa, Canada	8	104	13.00	6	2	25.00	0.74
9	Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences	7	69	9.86	5	1	14.29	0.56
10	China Medical University, Taichung, Taiwan	6	99	16.50	4	5	83.33	0.94
11	Institute of Organic Chemistry with Center of Phytochemistry 10CCP, Bulgaria	6	28	4.67	3	0	0.00	0.27
12	Sichuan University, China	6	73	12.17	2	2	33.33	0.69
13	University of Copenhagen, Denmark	6	95	15.83	4	3	50.00	0.90
14	The Norwegian Institute of Bioeconomy	6	60	10.00	3	3	50.00	0.57
15	China Pharmaceutical University, China	5	81	16.20	3	0	0.00	0.92
	Total of 15 organizations	136	3615	26.58	6.07	48.00	35.29	1.51
	Total of World	566	9954	17.59				
	Share of top 15 organizations in World total output	24.03	36.32					

TP=Total Papers; TC=Total Citations; CPP=Citations Per Paper; HI=h-index; ICP=International Collaborative Papers; RCI=Relative Citation Index.

- 9.06: Swedish Herbal Institute, Askloster, Sweden (21 papers), Medical University of Warsaw, Poland (14 papers), Corvinus University of Budapest, Hungary and University of Oulu, Finland (11 papers each), University of California, Irvine, USA and University of Camerino, Italy (10 papers each) during 2003-18.
- **Four organizations** registered citation impact above the group average of 36.58 citations per publication and relative citation index of 1.51 during 2004-18: Swedish Herbal Institute, Askloster, Sweden (71.57 and 4.07), Jiangnan University, China (33 and 1.88), University of Camerino, Italy (32.0 and 1.82) and University of Oulu, Finland (37.73 and 9.09).
- **Six organizations** contributed international collaborative publications share above the group average of 35.29%: China Medical University, Taichung, Taiwan (83.33%), Swedish Herbal Institute, Askloster, Sweden (80.95%), Corvinus University of Budapest, Hungary (63.64%), University of Copenhagen, Denmark and The

Norwegian Institute of Bioeconomy (50% each) and Medical University of Warsaw, Poland (35.71%) during 2003-18.

Profile of Top 15 Most Productive Authors

Three Hundred Seven (307) authors participated in global *Rhodiola rosea* research during 2003-18, of which 284 authors contributed 1-5 papers each, 20 authors 6-10 papers each and 3 authors 11-187 papers each.

The research productivity in the field of *Rhodiola rosea* research of top 15 most productive authors varied from 7 to 18 publications. Together they contributed 25.62% (145) global publication share and 42.08% (4189) global citation share during 1993-18. The scientometric profile of these 15 authors is presented in Table 5.

- **Four authors** registered publications output above the group average of 9.67: Z. Gyorgy and A. Panossian (18 papers each), G. Wikman (14 papers) and A. Hohtola (10 papers) during 2003-18.
- **Five authors** registered citation impact above the group average of 28.89 citations per publication and relative citation index of 1.64:

Table 5: Top 15 Most Productive Authors: Scientometric Profile on *Rhodiola rosea* during 2003-18.

S. No	Name of the Author		TP	TC	CPP	HI	ICP	%ICP	RCI
1	Z. Gyorgy	University of Oulu, Finland	18	123	6.83	7	13	72.22	0.39
2	Panossian	Swedish Herbal Institute, Sweden	18	1155	64.17	15	14	77.78	3.65
3	G. Wikman	Swedish Herbal Institute, Sweden	14	939	67.07	14	12	85.71	3.81
4	Hohtola	University of Oulu, Finland	10	187	18.70	7	1	10.00	1.06
5	Tolonen	University of Oulu, Finland	9	180	20.00	6	1	11.11	1.14
6	J.T. Arnason	University of Ottawa, Canada	8	99	12.38	5	2	25.00	0.70
7	L. Hu	Air Force College, Xuzhou, China	8	166	20.75	5	0	0.00	1.18
8	C. Ma	Jiangnan University, Wuxi, China	8	166	20.75	5	0	0.00	1.18
9	L. Mattioli	University of Camerino, Italy	8	281	35.13	8	1	12.50	2.00
10	M. Perfumi	University of Camerino, Italy	8	279	34.88	8	1	12.50	1.98
11	H. Wang	Jiangnan University, Wuxi, China	8	166	20.75	5	0	0.00	1.18
12	Cuerrier	University of Montreal, Canada	7	52	7.43	4	3	42.86	0.42
13	M. Furmanova	Medical University of Warsaw, Poland	7	205	29.29	5	4	57.14	1.66
14	M. Jafari	University of California, Irvine, USA	7	168	24.00	4	0	0.00	1.36
15	A. Pedryc Cornivas	University of Budapest, Hungry	7	23	3.29	3	5	71.43	0.19
	Total of 15 authors		145	4189	28.89	6.73	57	39.31	1.64
	Total of World		566	9954	17.59				
	Share of top 15 authors in World total output		25.62	42.08					

TP=Total Papers; TC=Total citations; CPP=Citations Per Paper; HI=h-index; ICP=International Collaborative Papers; RCI=Relative Citation Index.

G. Wikman (67.07 and 3.81), A. Panossian (64.17 and 3.65), L. Mattioli (35.13 and 2.00), M. Perfumi (34.88 and 1.98) and M. Furmanova (29.29 and 1.6) during 2003-18.

- **Six authors** contributed international collaborative publications share above the group average of 39.31% of all authors: G. Wikman (85.71%), A. Panossian (77.78%), Z. Gyorgy (72.22%), A. Pedryc Cornivas (71.43%), M. Furmanova (57.14%) and A. Cuerrier (42.86%) during 2003-18.

Medium of Research Communication

Of the total global output on *Rhodiola rosea* research, 96.11% (544) appeared in journals, 2.83% (16) in book series, 0.53% (3) in books, 0.35% (2) as trade publications and 0.18% (1) in conference proceeding during 2003-18. 544 journal papers appeared in 326 journals, of which 316 journals published 1-5 papers each, 5 journals 6-10 papers each, 3 journals 11-20 papers each and 2 journals 21-25 papers each during 2003-18. The top 15 most productive journals reported 4 to 25 papers each on *Rhodiola rosea* research; together they accounted for 26.65% (141 papers) of total *Rhodiola rosea* output published in journals during 2003-18, shown increase from 23.30% to 28.70% share between 2003-10 and 2011-18. The top ranking journal is Phytomedicine (with 25 papers), followed by Phytotherapy Research (21 papers), Evidence-based Complementary and Alternate Medicine (15 papers), Acta Horticulturae (13 papers), Planta Medica (11 papers), etc. during 2003-18 (Table 6).

Significant Keywords

77 significant keywords have been identified from the literature which through light on the research trends in *Rhodiola rosea* plant research including on its chemical composition, biological and pharmacological activity, traditional and official use of *Rhodiola rosea* L. in medicine. These keywords are listed in Table 7 in the decreasing order of the frequency of their occurrence in the literature during 2003-18.

Highly Cited Papers

Fourteen highly cited papers were identified each having 105 to 249 citations (13 papers each in citation range 105-200 and 1 paper with 249 citations) in 16 years during 2003-18. Together these 14 papers cumulated a total of 2029 citations, averaging 144.9 citations per paper. Of the 14 highly cited papers, 5 resulted from the participation of research organizations in their role as stand-alone (non-collaborating) institutional authors and remaining 9 from two or more research organizations working in their role as collaborating partners per paper (3 national collaborative and 6 international collaborative). Among 14 highly cited papers, the largest participation was seen from Sweden (7 papers), followed by Australia (3 papers) and Armenia, Canada, China, Germany, Italy, Morocco, Netherlands, Russian Federation, Spain and Switzerland (1 paper each). These 14 highly cited papers involved the participation of 59 personal authors and 32 research organizations in total across globe. Of the 14 highly cited papers, 9 were published as articles and 5 as review papers. These 14 highly cited papers were published in 11 journals, with 3 papers in Phytotherapy Research, 2 papers in Phytomedicine and 1 paper each in Biogerontology, Current Diabetes Review, Ecological Engineering, European Neuropsychopharmacology, Expert Opinion in Therapeutic Targets, Journal of Ethnopharmacology, Neurochemistry International, Nordic Journal of Psychiatry and Planta Medica.

CONCLUSION

The global publication data on *Rhodiola rosea* during the last 16 years showed that the annual and eight-year cumulative global output of *Rhodiola rosea* research registered 12.97% and 68.25% growth. Its global citation impact averaged to 17.59 citations per paper (CPP) in 16 years, which decreased from 29.57 CPP to 10.47 CPP from 2003-10 to 2011-18. The data for the study has been derived from the Scopus database with a view to study its quantitative and qualitative aspects.

Table 6: Top 15 Most Productive Journals Publishing on *Rhodiola rosea* during 2003-18.

S.No	Name of the Journal	Number of Papers		
		2003-10	2011-18	2003-18
1	Phyomedicine	8	17	25
2	Phytotherapy Research	12	9	21
3	Evidence-based Complementary and Alternate Medicine	2	13	15
4	Acta Horticulturae	2	11	13
5	Planta Medica	5	6	11
6	Bulletin of Experimental Biology and Medicine	1	7	8
7	Journal of Ethnopharmacology	3	6	9
8	Central European Journal of Immunology	6	0	6
9	Food and Chemical Toxicology	0	6	6
10	Zeitschrift Fur Phytotherapie	0	6	6
11	Biomedical Chromatography	3	3	6
12	Pharmaceutical Biology	3	2	5
13	Pharmaceutical Chemistry Journal	3	2	5
14	PLOS One	0	5	5
15	Acta Scientiarum Hortorum Cultus	0	4	4
	Total of 15 journals	48	97	145
	Total global journal output	206	338	544
	Share of top 15 journals in global journal output	23.30	28.70	26.65

More than 36% share of global output on *Rhodiola rosea* were from China and USA combined, whereas other 8 top ranking countries accounted each for global share between 4.06% and 7.60% during 2003-18. The top 10 most productive countries in *Rhodiola rosea* research together accounted for 83.04% global publication share and 89.95% global citation share during 2003-18. The global publication share of *Rhodiola rosea*, however, increased from 72.99% to 89.01% from 2003-10 to 2011-18. The global publication share registered an increase in China, U.K., Italy, USA and Taiwan (from 2.98% to 12.93%), as against decrease in Germany, Canada, Poland, Sweden and Russian Federation (from 0.16% to 4.51%) in eight years period (2003-10 and 2011-18). Of the top 10 countries, three registered relative citation index above the world average of 1.08: Sweden (2.78), Canada (1.17) and USA (1.11) during 2003-18. The international collaborative output of top 10 most productive countries in *Rhodiola rosea* research varied widely from 14.78% (China) to 70.27% (Germany) during 2003-18.

Medicine was the most sought after subject area of *Rhodiola rosea* research accounting for (44.88%) the highest publications share, followed by pharmacology, toxicology and pharmaceuticals (37.63%), biochemistry, genetics and molecular biology (32.69%), agricultural and biological sciences (21.02%), chemistry (12.72%), immunology and microbiology (6.18%) and neurosciences (4.77) during 2003-18. The research activities registered increase in biochemistry, genetics and molecular biology, agricultural and biological sciences, immunology and microbiology and neurosciences, as against decline of research activity in medicine, pharmacology, toxicology and pharmaceuticals and chemistry (from 115.49 to 90.79) from 2003-10 to 2011-18. Neuroscience, among various subjects registered the highest citations impact per paper of 32.52 CPP, followed by biochemistry, genetics and molecular Biology, pharmacology, toxicology and pharmaceuticals, chemistry, medicine, immunology and microbiology and agricultural and biological sciences during 2003-18.

The top 15 most productive research organizations and the authors on *Rhodiola rosea* research collectively contributed 24.03% and 25.62% global publication share and 36.32% and 42.08% global citation share

respectively during 2003-18. The leading organizations in terms of publication productivity were: Swedish Herbal Institute, Askloster, Sweden (21 papers), Medical University of Warsaw, Poland (14 papers), Corvinus University of Budapest, Hungary and University of Oulu, Finland (11 papers each), University of California, Irvine, USA and University of Camerino, Italy (10 papers each) during 2003-18. The leading organizations in terms of citation impact per paper and relative citation index were: Swedish Herbal Institute, Askloster, Sweden (71.57 and 4.07), Jiangnan University, China (33 and 1.88), University of Camerino, Italy (32.0 and 1.82) and University of Oulu, Finland (37.73 and 9.09). Similarly, the leading authors in terms of publication productivity were: Z. Gyorgy and A. Panossian (18 papers each), G. Wikman (14 papers) and A. Hohtola (10 papers) during 2003-18. The leading authors in terms of citation impact per paper and relative citation index were: G. Wikman (67.07 and 3.81), A. Panossian (64.17 and 3.65), L. Mattioli (35.13 and 2.00), M. Perfumi (34.88 and 1.98) and M. Furmanova (29.29 and 1.6) during 2003-18.

The journals medium accounted for 96.11% global share in *Rhodiola rosea* research with top 15 most productive journals accounting for 26.65% of total publications output in journals during 2003-18. Phytotherapy Research contributed the largest number of papers (25), followed by Phytotherapy Research (21 papers), Evidence-based Complementary and Alternate Medicine (15 papers), Acta Horticulturae (13 papers), Planta Medica (11 papers), etc. during 2003-18

Of the total *Rhodiola rosea* global research output, only 14 publications registered high citations, in the range of 105-249 citations per paper and collectively these highly cited papers received a total of 2029 citations, averaging to 144.9 citations per paper. These 14 highly cited papers involved the participation of 59 authors and 32 organizations and were published in 117 journals, of which with 3 papers in Phytotherapy Research, 2 papers in Phytotherapy and 1 paper each in 9 other journals. Concludes that further R&D studies on *Rhodiola rosea* are needed globally and in India with an aim to explore its cultivation and conservation

Table 7: List of Significant Keywords on Global *Rhodiola rosea* Research Literature during 2003-18.

S.No	Keyword	Frequency	S.No	Keyword	Frequency
1	<i>Rhodiola rosea</i>	392	41	Adaptogen	26
2	Rhodiola	283	42	Anti-inflammation Agent	26
3	Plant Extracts	260	43	Diabetes	26
4	Salidroside	133	44	Fluoxetine	26
5	Medicinal Plants	107	45	Anxiety Disorders	25
6	Drug Effects	94	46	Insomnia	25
7	Chemistry	87	47	Stress	25
8	Phytotherapy	84	48	Fluoxetine	23
9	Herbaceous Agent	81	49	Gene Expression	23
10	Drug Efficacy	74	50	<i>In vivo</i> Study	23
11	Depression	71	51	Physiology	23
12	Phenols	68	52	Mental Diseases	22
13	Rosavin	68	53	Flavonoids	21
14	Plant Root	68	54	Drug Isolation	20
15	Glycosides	63	55	Molecular Structure	20
16	Antioxidant Activity	61	56	Pathology	20
17	Drug Mechanism	59	57	Ageing	10
18	Rhodiolside	59	58	Herbs	19
19	Oxidation Stress	57	59	Alzheimer Disease	18
20	Fatigue	55	60	Antineoplastic Activity	17
21	Herbal Medicine	46	61	Mental Stress	17
22	Antioxidants	44	62	Headque	16
23	Drug Structure	42	63	Cardiovascular Diseases	14
24	Enzyme Activity	39	64	Immunomodulation	14
25	<i>In vitro</i> Study	39	65	Gallic Acid	14
26	Rosin	39	66	Xerostomia	11
27	Drug Response	38	67	Schizophrenia	11
28	Rhizome	38	68	Parkinson Disease	10
29	Tyrosol	38	69	Gastro-intestinal Disease	9
30	Drug Safety	37	70	Heart Palpitation	7
31	Phenol Derivatives	36	71	Heart Protection	6
32	Apoptosis	35	72	Ultraviolet Radiation	6
33	Rosarin	32	73	Urine Tract Disease	6
34	Neuroprotection	31	74	Digestive System Disease	3
35	Phytochemistry	31	75	Heart Muscle Necrosis	3
36	Clinical Trials	30	76	Gastro-intestinal Disease	9
37	Eleutherococcus Enticosus	30	77	Heart Palpitation	7
38	Enzyme Inhibition	30			
39	Hypercom Perforatum	29			
40	Antidepressant Agents	28			

potential and its potential capacity in preventing and treating multiple diseases. In future, more intensive research is needed in discovering its potential therapeutic effects and for developing new formulations.

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