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Economic benefits of animal pollination to Indian agriculture

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ABSTRACT

In an effort to estimate contribution of animal pollinators toward Indian agriculture, 211 crops (190 crops and 21 commodities) were analyzed using primary data. Production of 108 (51.2%) crops is dependent on animal pollination, 59 (28.0%) did not rely on it and for 44 (20.9%) information is not available. Among 108 crops, pollinator dependence was essential for 14 crops (6.6%, in absence 90-100% reduction in production occurs), great for 34 (16.1%), moderate for 29 (13.7%) and little for 31 (14.7%) crops. Rapeseed and mustard is the most pollinator dependent crop with an estimated economic value of pollination (EVP) of ₹ 19355.70 crores. Cotton, apple, citrus, guava, tomato, brinjal, chillies, okra, cumin, coriander, soybean are few of a large numbers of crops benefitted hugely by pollinators. Oilseeds greatly depend on insect pollination with 34.07% contribution to yield and resultant economic value of pollination (EVP) is estimated at ₹ 43993.08 crores from their total economic value (EV) of ₹ 129030.05 crores. Fruits follow with 14.82% (₹ 17095.45 crores) economic value mostly for 12 major fruits. Value of pollination from vegetables is ₹ 19498.20 crores (11.10%), fibers (mainly cotton) ₹ 17290.66 crores (23.39%) and condiments and spices at ₹ 10109.43 crores (25.47%). Huge research and information gap exists for these crops in India. Of the total value of Indian agriculture (₹ 1291369.63 crores at 2012-13 prices or USD 258.27 billion), proportion of animal pollinated crops is ₹ 422827.52 crores ($ 84.57 billion), representing 32.74%. Direct contribution of insect pollination to Indian agriculture is staggering ₹ 112615.73 crores (USD 22.52 billion) annually, representing 8.72%, besides spill over benefits of increase in quality traits, seed production, breeding efficiency, etc. For stagnant Indian agriculture, this "micro concept" of using honey bees for planned pollination of crops has the potential "macro-economic" impact.

Key words: Agriculture, Animal pollination, Economic value of output, Economic value of pollination, Honey bees, Pollinators

Beekeeping in the western world and India are poles apart. In the west it is based entirely on domesticated western honey bee (*Apis mellifera* L.), highly scientific using standard equipments, high colony holding, low labour-intensive, diversified and highly productive enterprise. It is practiced primarily for cross pollination of different crops, while honey and bees wax are its by products. On the contrary, Indian beekeeping is based on two domesticated species, viz. *A. mellifera* and Indian hive bee, *A. cerana indica* F. and two wild species - rock bees (*A. dorsata* F.) and dwarf honey bee (*A. florae* F.). Being a traditional industry, technology adoption rate is low and completely lacks the use of standard equipments. It is further characterized by extremely low colony holdings, moderately labour intensive with poor productivity and entirely lacks diversifications. Being entirely honey centric, it lacks emphasis on pollination service (Chaudhary 2007, 2014).

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Pollinators are now the proven providers of ecosystem services, enhance biodiversity and increase food production through cross pollination without threatening the environment. All these services are envisaged by United Nations Environment Program (UNEP 2011) from modern agriculture to achieve world's future food security, under threat from climate change (FAO 2010). Animal pollination has proved to be essential for food production directly as well as indirectly; supply of human food and animal feed resources (Daily 1997, Klein *et al*. 2007, Kremen *et al*. 2007, Aizen *et al.* 2009, Calderone 2012) which unfortunately are considered to be at risk now (Daily 1997, Palmer *et al.* 2004). Moreover, animal pollination is essential to the sexual reproduction of many cultivated crops (McGregor 1976, Crane and Walker 1984, Free 1993, Williams 1994, Nabhan and Buchmann 1997, Westerkamp and Gottsberger 2000) and majority of wild plants (Burd 1994, Kearns *et al.* 1998, Larson and Barrett 2000, Ashman *et al*. 2004) besides providing important calories and micronutrients to human beings and animals (Sundriyal and Sundriyal 2004, Ellis *et al*. 2015, Smith *et al*. 2015, Chaplin-Kramer *et al*.

2014). Pollinators greatly improve quality of fruits, nuts, oilseeds, vegetables, etc. thus, increase the economic value of crop production (Nagar and Chaudhary 2006, Klatt *et al*. 2013, Garratt *et al*. 2014).

Globally animal pollinated crops have been estimated to constitute 1/3rd of human diet (Klein *et al.* 2007). Since Levin (1967) reported economic benefits of bee pollination in USA at $ 6 billion and the value of honey and beeswax produced at $ 45 million only, many estimates have been made relying primarily on crude method of proportional contribution of pollinators to crop production (% increase in yield in bee pollinated plots compared to plots devoid of insect pollination). Goyal (1993) and Chaudhary (1998, 1999) provided subjective estimates of economic benefits from insect pollinators from 12 selected entomophilous crops at ₹ 2997 crores annually while Chaudhary (1998, 1999) also quantified the incidental pollination gains from existing stock of honey bee colonies at ₹ 1470 crores. However, such estimates are considered deceptive (Richards 2001, Ghazoul 2005, Borneck and Merle 1989, Robinson *et al*. 1989, Morse and Calderone 2000, Giannini *et al*. 2015, Gallai *et al*. 2009, Klein *et al*. 2007). Though it is impossible to quantify the real benefits by animal pollination due to many complexities but it is even harder to quantify the other benefits like ecosystem services as they are more qualitative in nature. Klein *et al.* (2007) using novel primary data from across the world improved upon this methodology which was further fine tuned by Gallai and Vaissiere (2009), Gallai *et al.* (2009), Vaissiere *et al*. (2011) and Giannini *et al.* (2015) but all these studies suffered from a basic flaw as they were based on one year data, that may not be the true representation of world facts. Eilers *et al.* (2011) further improved to make it more representative on a 10 year data base.

India with a growing population of more than 1.28 billion, world's 2.4% of geographic area, 4% water resources, 15% livestock, and 48.9% agriculture dependent population faces serious threat to future food security. Shrinking land base, stagnating production, no technological breakthrough in sight, rising stress on water resources, repeated droughts, huge deficits in oilseed and pulses production have put a great challenge amongst the agricultural scientists to keep pace of the desired national agriculture growth rate of 4 per cent and requirements of food security, besides the more ambitious initiative of the Prime Minister of India of doubling the profitability of Indian farmers by 2022 (Anon 2015 b).

As a source of livelihood, agriculture (including forestry and fishing) remains the largest sector of Indian Economy. While its output share fell from 28.3% in 1993-94 to 14.4% in 2011-12, employment share declined from 64.8% to 48.9% over the same period. Therefore, almost half of the workforce in India still remains dependent on agriculture. Given the low share of this workforce in the GDP, on average, it earns much lower income poorer than its counterpart in industry and services.

India is blessed with widest variety of flora (more than 6000 plants) and over 600 plants are designated as bee flora yielding over 70 types of unifloral and bifloral honeys (Kumar and Chaudhary 1993). India is also the home to widest variety of fauna, especially honey bees (being home to 3 of the 4 honey bee species of the world) and plant-pollinator interactions here may be substantially different from the west, where maximum pollination studies are undertaken. Apiculture in India is generally a poorly understood subject by policy planners owing to its miniscule proportion and lack of pressure groups and thus, did not find its richly deserved foot prints in main stream agriculture.

In this background, it is proposed to utilize the potential of honey bees in improving crop yields. Before embarking on the strategies to optimally use this resource, it is important that animal/insect pollinator's contribution to present Indian agriculture is estimated. Such an exhaustive but essential study is altogether lacking in India. Few previous estimates cover only a dozen important crops (Goyal 1993, Chaudhary 1998, 1999) and are subjective in nature. Recent world estimates (Klein *et al.* 2007, Eilers *et al.* 2011, Gallai *et al*. 2009) may not represent true Indian picture as majority of regional crops are not included in these studies. In this background, this paper is an attempt to quantify the benefits of animal pollination to Indian agriculture.

MATERIALS AND METHODS

Sourcing of crop production data: Data for agricultural crops of India was taken from many sources including Ministry of Agriculture and Farmers Welfare, Government of India; Directorate of Economics and Statistics (www.dacnet.nic.in), India Agri Stat (www.indiaagristat.com), Food and Agriculture Organization of the United Nations (www.faostat.fao.org) for the years 2000-01 to 2013-14. An effort was made to make this list as exhaustive as possible by including plants of economic importance, representing more than 99% of the crops. For minor pulses and oilseeds, the data was also taken from the web site of Indian Institute of Pulses Research, Kanpur (Anon. 2015 e) (www.iipr.nic.in) and Directorate of Oilseeds, Hyderabad (www.dor-icar.org.in), respectively (Anon. 2015 c). The data on major fruits and vegetables was additionally obtained from National Horticulture Board (www.nhb.gov.in) while for minor fruits and vegetables, from individual states where these crops are grown. For minor crops in a group (commodity), data from various state department of agriculture (SDA) was obtained.

Determination of annual mean production: From 14 year's crop production data, annual mean production of a crop was calculated with a view to provide more reliable and representative picture. Present study not only included a far longer time period of 14 years to make it more representative but also made the list of crops exhaustive (211 crops) by including majority of Indian origin crops compared to 124 (Klein *et al.* 2007), 141 (Gallai *et al.* 2009), 150 (Eilers *et al.* 2011) included in earlier studies.

Categories of crops and commodities: In present studies, individual crops were grouped together into categories, as a category with somewhat similar responses to inputs,

environment, pollinator regimen, etc. will help to better analyze these interaction and their impacts. Commodity constituted an aggregation of different crops (Klein *et al.* 2007) under a category with similar plant type or usage. These individual crops and commodities were grouped into eleven crop categories (in consonance with methodology adopted by Ministry of Agriculture) and included cereals, oilseeds, fruits, floriculture, vegetables, fiber crops, condiments and spices, drugs and narcotics, pulses, indigo and dyes, sugars and other crops. Some crops with multiple uses have been placed in one category only to avoid repetition except pea, that is included both under pulses and vegetables as data for both the commodities are available. The data was analysed for the 11 categories as well as for individual crops under various categories thus, making it more versatile. Previous studies discussed the impact of pollinators on individual crop basis only. This dual approach is more useful and envisaged in prioritizing policy decision making for future planned pollination initiatives.

Animal pollination data base of crops: For deriving the economic value of animal pollination, the data from many sources was taken. Data base provided by McGregor (1976), Crane and Walker (1984) and later by Free (1993) was considered who provided compiled information about 75 crops which was updated by Klein *et al.* (2007) to 137 world crops. Further, the values provided by Gallai *et al.* (2009) and Eilers *et al.* (2011) were also included. We extended this list and updated crop pollination status by including recent literature and those of earlier studies not cited, especially of Indian origin. Still many crops of Indian origin and cultivated mainly in India or Indian subcontinent do not find mention in above cited references. From Indian perspective, comprehensive review of Deodikar and Suryanarayana (1973) and Chaudhary (1998) besides other sources including reports from All India Coordinated Research Project on Honey Bees and Pollinators (Anon. 2013 b, Anon. 2015 g, Anon. 2016) were assessed. Majority of the Indian studies of quantification of benefits/contribution of animal pollination to Indian agriculture is primarily based on pollination experiments conducted under three sets of conditions a) where crop plots are caged to exclude the contact of pollinating agents, b) crop plots are not caged and exposed to all pollinating agents, and c) crop plots caged with honey bee colony. However, they do not confirm to the internationally recognized protocol (Delaplane *et al*. 2013) as it lacked mandatory inclusion of hand pollination and other treatments. Such studies were thus, included only in cases where optimum data for the crops were unavailable.

Crop grouping based on animal pollination dependence: Based on the fact that economic impact of pollinators in increasing crop yields is quantifiable and any lack could result in reduction of yield as well as quality (Free 1993), grouping of crops based on degree of dependence on pollinators is made. Earlier studies (Levin 1967, Borneck and Bricout 1984, Robinson *et al*. 1989, Goyal 1993, Chaudhary 1998, 1999, Southwick and Southwick 1992, Morse and Calderone 2000) relied purely on product of per cent increase in yield and crop's economic value to quantify the value of animal pollination, which being subjective assessment was fraught with many flaws. Klein *et al*. (2007) further refined the process by combining empirical yield data and crop values to work out reduction in yield in crops in absence of animal pollination. They grouped crops into following six groups (Table 1), besides assessing other effects on production of plant parts and increase in seed production and improvement in breeding efficiency. Eilers *et al*. (2011) employing bio-economic approach, assigned median point to above categories as the contribution of pollinators for the respective groups while Gallai *et al.* (2009) further converted them into "dependence rate (DR)" for each category.

FAO (Gallai and Vaissiere 2009, Vaissiere *et al*. 2011) based on the previous studies, further refined the guidelines for the economic valuation of pollination services at a national scale. Employing a combination of above methodology, all the crops were assigned respective dependence rate (DR) values (Table 1). In some crops where variations in pollination values in different studies over geographic regions were encountered, the extreme values were omitted and the median values were derived at and assigned to various groups. In crops that are wind pollinated (especially cereals) or with vegetative reproduction or parthenocarpic, a separate category of "no increase" was designated with a DR of 0.00. Still there were many crops where pollination dependence was not studied, especially for commodities and they were referred to as another group

Table 1 Grouping of crops based on dependence on animal pollination

Groups	Range of yield reduction (%) without flower visitors (pollinators)		Dependence rate (DR)	Present studies, dependence rate (DR)
	Klein *et al*. (2007)	Eilers *et al*. (2011) Mean value	Gallai *et al.* (2009), Gallai and Vaissiere (2009), Vaissiere *et al*. (2011)	
Essential	90-100	95	0.95	0.95
Great	40-90	65	0.65	0.65
Modest	10-40	25	0.25	0.25
Little	0- 10	5	0.05	0.05
No increase		0	0.00	0.00
Unknown				0.00

termed "unknown". Previously, this group was not assigned any value, but in this study, the DR value of 0.00 was given.

Cotton is primarily produced for lint and cottonseed as a by-product is an important source of edible oils besides animal feed. Cottonseed yield was computed as per norms of Indian Institute of Cotton Research, Nagpur (Agarwal and Gopalakrishnan 2007). In case of crops where pollination resulted in increased fruit quality (shape, size, sweetness, number of seeds, taste, reduction in malformed fruits, increase oil content, etc.), the benefits are subjectively mentioned as there were hardly any studies on the economical value of these increased benefits, but such benefits could be very extensive. Similarly, crops where breeding efficiency and seed production significantly increased due to pollination are also mentioned without any economic value of increased output, for want of empirical data.

Determination of economic value of pollination: The economic value of output (EV) of different crops and categories were obtained (Anon. 2013 a) from the website of Ministry of Statistics and Programme Implementation, Government of India (www.mospi.gov.in) and Directorate of Economics and Statistics (Anon., 2015a), Department of Agriculture, Cooperation and Farmers Welfare, Ministry of Agriculture and Farmers Welfare (www.dacnet.nic.in). These EV's were considered at current prices (in rupees) for the year 2012-13. These EV's were derived by multiplying the quantum of production with the farm gate price (equation 1). Farm gate price was the mean of crop/commodity price collected from designated collection centers spread over the country by the Central Statistical Organization for the purpose of national accounting. For many crops, the production and value data were either unknown or grouped into "other crops" and were thus, credited either as unknown or assigned the respective group value.

$$EV = QT \times FGP \quad 1$$

where EV= Economic value of annual crop output, Qt = Production quantum of crop annually, FGP = Farm gate price.

Economic value of pollination service (EVP) for a crop was derived at by multiplying economic value (EV, equation 1) of annual crop production thus obtained with dependence rate (Table 1).

$$EVP = EV \times DR \quad 2$$

where DR= Dependence ratio.

In case the production values for a crop were not available for all the years of designated period (2000-01 to 2013-14), the available values for any duration of the period were taken. The crops with no database available either for annual production, farm gate price, economic value or dependence rate, were marked "unknown" to garner insight about the unexplored frontiers where important work needed to be initiated.

Determination of role of pollinating agents in crops: In order to ascertain the role of various pollinating agents or floral visitors including insects, bees, birds, etc. in crop pollination, primary data compiled by Free (1993), later modified by Klein *et al.* (2007) pertaining to 107 crops and commodities with further inputs from Deodikar and Suryanarayana (1973), Chaudhary (1998) and many others including reports of All India Coordinated Research Project on Honey bees and Pollinators (Anon. 2013 b, Anon. 2015 g, Anon. 2016) was analyzed. Diversity of pollinating agents was segregated over respective crops and collated into frequencies of floral visitors that probably effected crop pollination. The data is qualitative only without taking into account their abundance thus, indicative. Determination of these prominent groups would help orient efforts in their employment in planned pollination initiatives.

RESULTS AND DISCUSSION

Based on the analysis of a total of 211 crops (190 crops and 21 commodities), it was emphatic to find more than half the crops (108, 51.2%) needing animal pollination for their production of fruits, seeds, nuts, etc. (Table 2). Insect pollination dependence for 44 (20.9%) crops could not be ascertained (unknown) due to lack of research studies or non-availability of information. Only 28.0% (59) crops did not-dependent on bee pollination for their production as they were mainly passively self or wind pollinated or parthenocarpic or consumed in vegetative stage.

In terms of economic value, the trend however, reversed (Table 3) as 28.0% of the non animal pollination dependent crops accounted for 50.55% of value (₹ 652742.12 crores) of total agriculture output of the country (₹ 1291369.63 crores). Animal pollinated crops represented only 31.76% of value (₹ 410094.77 crores) and even for the unknown segment, the value was huge at ₹ 228533.15 crores (17.70%).

Dwelling further into the degree of dependence (Table 2) of 108 entomophilous crops revealed that insect pollination was essential for 14 (6.6%) crops, as in their absence, a reduction of 90-100% in their yield occurred. Dependence of 34 crops (16.1%) was great (reduction of 40-90%) and for 29 (13.7%) was modest (10-25% reduction). Pollinators were of little importance to only 31 (14.7%) crops (reduction of up to 10% in yield). Considering their economic value (Table 3), the modest (₹ 2 21 956.48, 17.19%) and little pollination dependent crops (₹ 127 135.24 crores, 9.84%) garnered maximum value followed by crops with great dependence (₹ 72 636.37 crores, 562%). Essentially pollinator dependent crops were of least value of ₹ 1334.68 crores.

When analyzed on the basis of dependence rate (Table 4), i.e. actual contribution of insect pollination in crop's yield (economic value of proportion of crop production that might have been lost in absence of pollinators), the scenario changed. Maximum values were from crops with modest (₹ 54 149.17 crores, 48.08%) and great (₹ 50 697.50 crores, 45.02%) pollination benefits. Such value from little pollination dependent crops became considerably lower (₹ 6501.10 crores, 5.77%). The minimum contribution (1.13%) was from essentially dependent crops (₹ 1267.95 crores).

Individual crops, based on their interaction to animal pollination were evaluated for economic value (EV) of

Table 2 Scenario of animal pollination dependent crops in India

Crops / commodities	No. of			Crops status with respect to animal pollination (AP) dependence						
	Crops	Commodities	Total	Essential	Great	Modest	Little	AP dependent	Unknown	No increase
Cereals	14	2	16	0	1	0	0	1	0	15
Oilseeds	14	1	15	0	4	7	2	13	1	1
Fruits	51	4	55	3	20	9	9	41	10	4
Floriculture	0	1	1	0	0	0	0	0	1	0
Vegetables	48	2	50	7	2	5	5	19	10	21
Fibres	4	1	5	0	0	2	0	2	1	2
Condiments and spices	27	1	28	3	7	2	4	16	6	6
Drugs and narcotics	8	1	9	1	0	1	1	3	4	2
Pulses	17	1	18	0	0	2	8	10	5	3
Indigo and dyes	1	0	1	0	0	1	0	1	0	0
Sugars	2	1	3	0	0	0	0	0	0	3
Other crops	4	6	10	0	0	1	1	2	6	2
Grand total	190	21	211	14	34	29	31	108	44	59

Table 3 Summary of economic value of animal pollination services to Indian agriculture

Crops exhibiting effect of animal pollination	Economic value of crops(₹ crores)	Proportion of total value of output of agriculture (%)
No increase	652 742.12	50.55
Unknown	228 533.15	17.70
Bee pollinated	410 094.77	31.76
Essential	1 334.68	0.10
Great	72 636.37	5.62
Modest	221 956.48	17.19
Little	127 135.24	9.84
Total value of agriculture output (EV)	1291 369.63	

output to ultimately determine the economic value of pollination (EVP). Such benefits for individual crops as well as their respective assigned category are presented here.

Cereals and millets: This category included 14 crops and 2 commodities (Table 5) and comprised six major crops, five of them cereals (rice, wheat, barley, sorghum and maize) while bajra was the major millet. Cereals and millets, as a group, being the major staple food are the single largest contributor (28.33%) to the total output value of agriculture in India. Being self or wind pollinated crops, they do not require animal pollination to set seeds except buckwheat or *kuttu* (a minor pseudocereal) that depends greatly on honey bee for its pollination (Goodman *et al*. 2001). However, in absence of data regarding output value, its EVP remains elusive.

Oilseeds: Oilseeds are the fourth largest contributor (10.0%) to the national agriculture valued at ₹ 129 143 crores (Table 2 and 6). By including oil output from cottonseed (a by-product of cotton), actual worth of oilseeds is ₹ 141 269.27 crores. All these 15 oilseeds (14 crops and 1 commodity) were dependent on animal pollination except olive (Table 6). Their pollination dependence gradient can be gauged from the fact that 4 crops, viz. rapeseed and mustard, sunflower, niger and *taramira* depended greatly on pollinators for their production (DR=0.65, 40-90% yield reduction in absence of pollinators). Seven oilseeds (sesame, castor, safflower, soybean, coconut, linseed and cotton as cottonseed) were modest in their dependence (DR=0.25, 10-40%). Out of these ten, seven are the major oilseeds. Dependence of only 2 oilseeds (groundnut and oil palm) was little (DR=0.05, 0-10%) while such values for 1 minor commodity was yet to be fully established.

While considering individual oilseed crops, insect pollinators greatly increase the yield (DR=0.65) of two major oilseeds - mustard and sunflower- known for their high quality oil. In mustard, with a mean production of 6.64 million tonnes, valued at ₹ 29 778 crores, the economic value of animal pollination is huge at ₹ 19 355.70 crores. While for sunflower, ₹ 1 153.40 crores is contributed by animal pollinators from its total economic value of ₹ 1 774 crores. Together from these two crops, EVP is estimated at ₹ 20 509.09 crores out of their total EV of ₹ 31 552.45 crores (65%).

In other 6 major oilseeds, viz. sesamum, castor, coconut, linseed, soybean and cottonseed, even with modest dependence on animal pollinators (DR=0.25, reduction of 10-40% in yield), EVP of ₹ 18 821.69 crores is estimated from their total output value of ₹ 75 286.77 crores. The EVP in sesamum, linseed and safflower with modest dependence was estimated at ₹ 1071.58, 180.43 and 58.30 crores,

Table 4 Economic value of animal pollination services based on dependence rate of crops to Indian agriculture

Crop categories	Economic value based on crop's dependence rate on animal pollination (₹ crores)				
	Essential	Great	Modest	Little	Total
Cereals	0.00	0.00	0.00	0.00	0.00
Oilseeds	0.00	20834.68	21941.57	1216.82	43993.08
Fruits	0.00	11797.76	3096.89	2247.62	17142.27
Vegetables	0.00	11977.90	7445.46	74.84	19498.20
Fiber	0.00	0.00	17290.66	0.00	17290.66
Sugar	0.00	0.00	0.00	0.00	0.00
Indigo and dye	0.00	0.00	27.25	0.00	27.25
Condiments and spices	1104.70	6087.15	2520.25	409.09	10121.19
Drug and narcotics	163.25	0.00	1818.92	4.81	1986.97
Pulses	0.00	0.00	0.00	1236.13	1236.13
Others	0.00	0.00	8.19	1311.80	1319.99
Total	1267.95	50697.50	54149.17	6501.10	112615.73
% of total EV	0.10	3.93	4.19	0.50	
% of EVP	1.13	45.02	48.08	5.77	

Table 5 Pollination dependence of Indian crops and economic value of pollination – Cereals

Crops / commodities	Botanical name	Mean production	Dependence on animal pollinators	Dependence rate	Economic value (₹ crores)*		Other benefits (Quality) increase
					Crop output	Pollination service	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rice	*Oryza sativa* L.	93.22**	No increase[1]	0.00	182407	0.00	
Wheat	*Tritcum aestivum*	78.95	No increase [1]	0.00	131184	0.00	
Triticale	*Triticosecale rimpani*		No increase [1,2]	0.00		0.00	
Barley	*Hordeum vulgare* L.	1.46	No increase [1]	0.00	2155	0.00	
Sorghum	*Sorghum vulgare* Pers.	6.86	No increase [3]	0.00	8309	0.00	
Maize	*Zea mays* L.	17.20	No increase [1]	0.00	27892	0.00	
Millet			No increase [1]	0.00		0.00	
Pearl millet, bajra	*Pennisetum typhoides* (Burn. F.) S. & H	8.57	No increase [3]	0.00	11034	0.00	
Ragi, finger millet	*Eleusine coracana* (L.) Gaertn.	1.97	No increase [3]	0.00	2266	0.00	
Italian millet, fox tailed millet	*Setaria italica* (L.) Beauv.)					0.00	
Branyard millet, sanwa	*Echinochloa frumentacea* (Roxb.)					0.00	
Kodo millet, kodara	*Paspalum scrobiculatum* L.					0.00	
Common millet	*Panicum miliaceum* L.					0.00	
Little millet	*Panicum miliare* Lamk					0.00	
Oat	*Avena sativa* L.		No increase [1]	0.00		0.00	
Buckwheat, kuttu	*Fagopyrum esculentum* Moench		Great[1]	0.65		0.00	
Small millets		0.48	No increase [3]	0.00	453	0.00	
Total coarse cereals		36.62	No increase [3]	0.00	93	0.00	
Total cereals		208.79			365793	0.00	
Percent increase due to pollination						0.00	

*Economic value at current prices 2012-13, **Mean of values from 2000-01 to 2013-14, ***Production is in million tonnes. Dependence on animal pollinators: [1]Klein *et al.* (2007); [2]Gallai and Vaissiere (2009); [3]Chaudhary (1998), Deodikar *et al.* (1972), Anon. (2014) and other Indian sources. Blank values refer to non-availability of information.

Table 6 Pollination dependence of Indian crops and their economic value of pollination – Other crops

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Oilseeds (Production million tonnes)							
Major oilseeds							
Rapeseed and mustard	*Brassica campestris* L.	6.64	Great[1,3]	0.65	29778.00	19355.70	Seed no. and weight, oil content, early maturity
Castor seed	*Ricinus communis*	1.14	Modest[2]	0.25	8894.00	2223.58	Fruit, oil quantity and quality
Sunflower	*Helianthus annuus*	0.91	Great[2]	0.65	1774.00	1153.40	Oil, protein quantity, germination
Sesamum	*Sesamum indicum*	0.67	Modest[1,3]	0.25	4286.00	1071.58	Seed production
Cottonseed (Prod. excluded but not EVP)	*Gossypium* sp.	7.37	Modest[1]	0.25	12968.00	3242.00	Seed no., oil. Reduce moles and boll shedding
Coconut (Prod. hundred million nuts)	*Cocos nucifera*	150.66	Modest[1]	0.25	11270.00	2817.38	
Soybean	*Glycine max, G. soja*	9.29	Modest[1]	0.25	50115.00	12528.72	Seed production
Groundnut	*Arachis hypogaea*	6.91	Little[1]	0.05	20728.00	1036.40	
Linseed, alsi	*Linum usitatissimum*	0.17	Modest[3]	0.25	722.00	180.43	
Total					127567.00	43609.18	
Increase in production due to animal pollination (%)						34.19	
Minor oilseeds							
Taramira	*B. juncea*		Great[3]	0.65	175	114.04	
Safflower	*Carthmus tinctorius*	0.17	Modest[3]	0.25	233	58.30	
Niger seed	*Guizotia abyssinica* (L.f.) Cass.	0.11	Great[3]	0.65	325	211.55	
Oil palm	*Elaeis guineensis*		Little[1,2]	0.05		0.00	
Olive	*Olea europaea*		No increase[1]	0.00		0.00	
Others			Unknown[1]	0.00	842	0.00	
Total minor oilseeds					1576	383.89	
Increase in production due to animal pollination (%)						24.36	
Total oilseeds					129143.00	43848.73	
Increase in production due to animal pollination (%)						33.95	
Fruits (Production thousand tonnes)							
Major fruits							
Almond	*Amygdalus communis*	11.13	Great[2,3]	0.65	130.08	84.55	
Aonla	*Emblica officinalis* Gaertn	1269.645	Unknown[3]	0.00		0.00	
Apple	*Pyrus malus*	1835.90	Great[1,3]	0.65	5577.16	3625.15	
Banana	*Musa paradisica* L.	21651.19	No increase[2]	0.00	28602.59	0.00	
Ber, jujube	*Zizyphus mauritiana* Lamk.	412.095	Modest[2]	0.25		0.00	
Blue berries, bilberry	*Vaccinium corymbostum* V. sp.	1839.85	Great[1]	0.65		0.00	
Cashewnut	*Anacardium occidentale*	612.24	Great[1,2]	0.65	5359.79	3483.87	
Lemon	*Citrus limon* (L.) Burns, F.	2047.65	Little[1,3]	0.05	4913.07	245.65	
Lime	*Citrus aurantifolia*		Unknown[3]	0.00		0.00	
Kinnow, mandarin	*Citrus reticulata*		Little[1,3]	0.05		0.00	

Contd.

Table 6 (*Continued*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Mosambi, sweet lime	*Citrus limetta*	2364.59	Great[1,3]	0.65	3464.16	2251.70	
Orange	*Citrus aurantium, C. sinensis*	1946.29	Modest[2,3]	0.25	9330.67	2332.67	
Other citrus fruits		980.06	Little[1,3]	0.05	716.31	35.82	
Grapes	*Vitis vinifera*	1634.36	No increase[1]	0.00	3620.07	0.00	
Guava	*Psidium guajava*	2205.87	Great[2,3]	0.65	2858.93	1858.31	
Litchi, lychee	*Litchi cginensis*	457.95	Modest[2,3]	0.25	3056.87	764.22	
Mango	*Mangifera indica*	13722.77	Little[1,2,3]	0.05	35514.74	1775.74	
Musk melon	*Cucumis melo* L.	762.90	Essential[1,2]	0.95		0.00	
Papaya	*Carica papaya*	3250.58	Little[1]	0.05	3808.31	190.42	
Peach, nectarine	*Prunus persica, P. laevis*	193.26	Great[1,2,3]	0.65		0.00	
Pear	*Pyrus communis*	261.99	Great[1]	0.65	688.26	447.37	
Pineapple	*Ananas comosis*	1349.84	No increase[2]	0.00	2816.60	0.00	
Plum	*Prunus domestica, P. spinosa*	152.17	Great[1,2]	0.65		0.00	
Pomegranate	*Punica granatum*	869.70	Modest[1]	0.25		0.00	
Sapota		1184.08	Unknown[3]	0.00	2388.65	0.00	
Walnut	*Juglans regia*	34.08	Unknown[3]	0.00	2542.45	0.00	
Water melon	*Citrullus lanatus* (Thnub.) *Mansf.*	301.97	Essential[1,2]	0.95		0.00	
Total major fruits					115388.72	17095.45	
Increase in production due to animal pollination (%)						14.82	
Minor fruits							
Apricot	*Prunus armeniaca*	13.22	Great[1,2]	0.65		0.00	
Avocado	*Peersea americana*		Great[1,2]	0.65		0.00	
Jatropha	*Jatropha curcas*		Great[2]	0.65		0.00	
Black mulberry	*Morus nigra, Rubus ulmifolius*		Modest[2]	0.25		0.00	
Carambola	*Averrho acarambola* L.		Great[1]	0.65		0.00	
Cherry	*Prunus cerasus, P. avium*	10.49	Great[1,2,3]	0.65	72.03	46.82	
Chestnut	*Castanea sativa*		Modest[1]	0.25		0.00	
Pumello	*C. grandis*		Unknown[3]	0.00		0.00	
Grape fruit	*C. maxima* (Burn) Merrill.		Unknown[3]	0.00		0.00	
Currant black/red	*Ribes nigrum, R. rubrum*		Modest[1]	0.25		0.00	
Date palm	*Phoenix dactylifera*		No increase[1]	0.00		0.00	
Fig	*Ficus carica* L.	14.25	Modest[1]	0.25		0.00	
Hog plum, Mombin	*Spondias mombin, S. tuberosa*		Modest[1,2]	0.25		0.00	
Jamun	*Syzygium malaccense*		Great[1]	0.65		0.00	
Kiwi fruit	*Actinidia deliciosa*	8.24	Essential[1,3]	0.95		0.00	
Loquat	*Eriobotrya japonica* (Thunb) Lindl.		Great[1]	0.65		0.00	
Persimon	*Cavanillea philippensis, Diospyros kaki*		Little[1]	0.05		0.00	
Phalsa	*Grewia asiatica* L.		Unknown[3]	0.00		0.00	
Bael	*Aegel marmelos*		Great[1]	0.65		0.00	
Rambutan	*Nephelium lappaceum*		Little	0.05		0.00	
Raspberry	*Rubus ideaus*		Great[1]	0.65		0.00	

Contd.

Table 6 (*Continued*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rose hips, dogroses	*Rubus idaeus*		Great[1]	0.65		0.00	
Soursop	*Annona muricata*		Little[2]	0.05		0.00	
Star apple, cainito	*Chrysophyllum cainito, Achras caimito*		Little[1]	0.05		0.00	
Strawberry	*Fraggaria* spp.		Great[1,2]	0.65		0.00	
Other temperate fruits			Unknown[3]	0.00	124.30	0.00	
Subtropical fruits			Unknown[3]	0.00	9.44	0.00	
Other fruits		6821.51	Unknown[3]	0.00	13435.55	0.00	
Total minor fruits					13641.33	46.82	
Percent increase due to pollination (%)						0.34	
Total fruits					129030.05	17142.27	
Percent increase due to pollination (%)						13.29	
Floriculture					19193.83	0.00	
Vegetables (Production 000 MT)							
Major vegetables							
Bean	*Phaseolus lunata, P. angularis, P. caltuscar*	494.38	Little[1]	0.05		0.00	
Bottle gourd	*Lagenaria siceraria* Standl		Essential[1,2]			0.00	
Bitter gourd	*Momordica charantia* L.		Essential[1,2]			0.00	
Cabbage	*Brassica oleracea* L. var. *capitata*	6678.69	No increase[1]		11013.87	0.00	
Carrot	*Daucus carota*		No increase[2]	0.00		0.00	
Cauliflower	*Brassica oleracea* L.	5984.17	No increase[2]	0.00	13101.26	0.00	
Chile pepper (Red, bell, green)	*Capsicum annuum*		Little[2]	0.05		0.00	Increase fruit weight
Arbi, coco yam	*Colocasia esculenta*		No increase[2]			0.00	
Cucumber, gherkins	*Cucumis sativus* L.		Great[1,2,3]	0.65		0.00	
Custard apple	*Annona squamosa*	155.88	Essential[1]	0.95		0.00	
Eggplant, brinjal	*Solanum melongena* L.	10146.00	Modest[1,2]	0.25	19367.90	4841.97	
Jack fruit	*Artocarpus heterophyllus* Lam.	1238.43	Unknown[1]	0.00	1654.21	0.00	
Okra, lady's finger	*Abelmoschus esculentus*	4525.68	Modest[1]	0.25	10413.94	2603.48	
Onion (Million MT)	*Allium sepa* L.	10.52	No increase[2,3]	0.00	14727.86	0.00	Seed production
Peas	*Pisum sativum*	2799.90	No increase[2]	0.00	7781.58	0.00	
Potato(Million MT)	*Solanum tuberosum*	30.90	No increase[2]	0.00	33633.31	0.00	
Pumpkin, squash and gourds	*Cucurbita maxima, C. mixta, C. moschata, C. pepo*	3791.41	Essential[1,2]	0.95		0.00	Germination, vigour
Radish	*Raphanus sativus* L.		No increase[3]	0.00		0.00	Seed production
Palak, spinach	*Spinacia olearacea*		No increase[2]	0.00		0.00	
Sweet potato	*Ipomoea batatas*		Little[1]	0.05	1496.72	74.84	
Tomato	*Lycopersicon esculentum* Mill.	11819.63	Great[2,3]	0.65	18427.54	11977.90	
Tapioca, cassava	*Manihot esculenta*	7501.58	No increase[2]	0.00	4956.67	0.00	
Turnip	*Brassica rapa*		No increase[1]			0.00	
Roots and tubers			No increase[1]			0.00	
Other vegetables			Unknown[1]		39159.60	0.00	

Contd.

Table 6 (*Continued*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Total major vegetables					175734.46	19498.20	
Increase in production due to animal pollination (%)						11.10	
Minor vegetables							
Arrowroot	*Maranta arundinacea*		Unknown[3]	0.00	0.00	0.00	
Artichoke	*Cynara scolymus*		No increase[2]	0.00		0.00	
Asparagus	*Asparagus officinalis*		No increase[2]	0.00		0.00	
Atemoya	*Annona squamosa*		Essential[2]	0.95		0.00	
Balsamapple	*Momordica charantia*		Modest[1]	0.25		0.00	
Broccoli	*Brassica chinensis*		No increase[1]	0.00		0.00	
Sponge gourd	*Luffa cylindrica* L.		Essential[1,2]	0.95		0.00	
Capers (Fresh)	*Capparis spinosa*		No increase[2]	0.00		0.00	
Caraway	*Carum carvi*		Modest[1]	0.25		0.00	
Carddons	*Cynara cardunculus*		Unknown[1]	0.00		0.00	
Brussels sprout	*Brassica chinensis*		No increase[1]	0.00		0.00	
Drumstick	*Moringa oleifera* L.		Unknown[3]	0.00	43.35	0.00	
Lettuce	*Lactuca sativa, Cichorium intybus, C. endivia*		No increase[2]	0.00		0.00	
Medlar	*Mespilus germanica*		Unknown[1]	0.00		0.00	
Oyster plant	*Tragopogon porrifolius*		Unknown[1]	0.00		0.00	
Parsley	*Petroselinum crispum* (Mill)		Modest[1]	0.25		0.00	
Bathua, Pigweed	*Chenopodium album* L.		Unknown[3]	0.00		0.00	
Pimenta	*Capsicum chinense*		Little[1]	0.05	0.00	0.00	
Quinoa	*Chenopodium quinoa*		No increase[2]	0.00		0.00	
Snakeguard	*Trichosanthes cucumerina* L.		Essential[1]	0.95		0.00	
Velvet bean	*Mucuna ruriens*		Unknown[1]	0.00		0.00	
Winged bean	*Psophocarpus tetragonolobus* (L.)		Little[1]	0.05		0.00	
Yam	*Dioscorea* spp.		No increase[2]	0.00		0.00	
Yam bean, Mishrikand	*Pachyrrhizus erosus*		Unknown[1]	0.00		0.00	
Yerba mate	*Ilex paraguariensis*		No increase[1]	0.00	0.00	0.00	
Total major vegetables					43.35	0.00	
Increase in production due to animal pollination (%)						0.00	
Total vegetables					175821.16	19498.20	
Increase in production due to animal pollination (%)						11.09	
Fibre crops (Production 000 tonnes)							
Cotton (Million Bales of 170 kg each)	*Gossypium hirsutum, G.* sp.	22.14	Modest[1,2,3]	0.25	69119.16	17279.79	Increase quality, seed, oil content
Jute (Million Bales of 180 kg each)	*Corchorus* spp.	10.24	No increase[2]	0.00	4538.02	0.00	
Mesta		0.84	No increase[2]	0.00	180.43	0.00	
Sann hemp	*Crotalaria juncea* L.	58.64	Modest[3]		43.46	10.87	
Other fibers			Unknown[1]		35.98	0.00	
Total fibers					73917.05	17290.66	
Increase in production due to animal pollination (%)						23.39	

Contd.

Table 6 (*Continued*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Sugars							
Sugarcane	*Saccharam officinarum* L.	307.89	No increase[1]	0.00	80787.03	0.00	
Sugar beat	*Beta vulgaris* L.		No increase[1]	0.00			
Others			No increase[1]	0.00	184.90	0.00	
Total Sugars					80971.92	0.00	
Increase in production due to animal pollination (%)						0.00	
Indigo and dyes							
Indigo	*Indigofera tinctoria*		Modest[1]	0.25	109.00	0.00	
Increase in production due to animal pollination (%)						0.00	
Condiments and spices (Production tonnes)							
Major spices							
Arecanut	*Areca catechu*	490533	Little[1]	0.05	5311.59	265.58	
Cardamom (Small)	*Elettaria cardamomum*	12091.0	Essential[3]	0.95	1162.85	1104.70	
Cardamom (Large)	*Amomum subulatum* Roxb.	4080.6	Unknown[1]	0.00		0.00	
Celery	*Trachyspernum roxburghianum*	5193.4	Great[1]	0.65		0.00	
Black pepper	*Capsicum annuum*		Little[1]	0.05	1836.77	91.84	
Chillies	*Capsicum annuum*	1395537.8	Modest[1]	0.25	10081.00	2520.25	
Clove	*Syzygium aromaticum*	964.8	No increase[3]	0.00	7.56	0.00	
Coriander	*Coriandrum sativum* L.	455458.6	Great[1,3]	0.65	2384.00	1549.79	
Cumin	*Cuminum cyminum* L.	369532.4	Great[1]	0.65	6198.80	4029.22	
Fennel	*Foeniculum vulgare*	122123	Great[1,3]	0.65	357.18	232.17	
Garlic	*Allium seativum*	1044710	No increase[3]	0.00	1817.23	0.00	Breeding efficiency
Ginger (Dry)	*Zingiber officinale*	809504	No increase[3]	0.00	2812.17	0.00	
Fenugreek, methi	*Trigonella foenum graecum L.*	109801.4	Little[3]	0.05	235.25	11.76	
Nutmeg	*Myristica fragrans* Houtt	11917.8	Great	0.65	424.58	275.98	
Pepper	*Piper nigrum, P, longum*	51200	Little[1]	0.05		0.00	
Tamarind, imli	*Tamarindus indica* L.	179123.2	Little[1]	0.05	798.11	39.91	
Ajwain, thyme	*Trachyspernum ammi L.*	20249.6	Unknown[1]		66.87	0.00	
Turmeric	*Curcuma longa* L.	1095266.8	No increase[3]		4135.19	0.00	
Total major spices		6177287.97			37629.42	10109.43	
Increase in production due to animal pollination (%)						26.90	
Minor spices							
Allspice, Pimento	*Pimenta dioica*		Great[1]	0.65		0.00	
Anise	*Pimpinella anisum* L.		Great[1]	0.65		0.00	
Asparagus	*Asparagus officinalis*		No increase[2]	0.00		0.00	Seed production
Caraway	*Carum carvi*		Modest[1]	0.25		0.00	
Dill (seed)	Anethum graveolens *L.*	20996.00	Essential[1]	0.95		0.00	
Grains of paradise	*Afromomum melegueta* Rose		Unknown[2]			0.00	
Rye	*Secale cereale*		No increase[1]	0.00		0.00	
Star anice	*Illicium verum*		Unknown[1]	0.00		0.00	
Vanilla	*Vanilla planifolia, V. pompona*		Essential[1]	0.95		0.00	
Other condiments and spices			Unknown[3]	0.00	2055.16	0.00	
Increase in production due to animal pollination (%)						0.00	

Contd.

Table 6 (*Continued*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Total spices					39684.57	10109.43	
Increase in production due to animal pollination (%)						25.50	
Drugs and narcotics (Production 000 tonnes)							
Coffee	*Coffea arabica, C. canephora, C. liberica*	287.20	Modest[1,2]	0.25	7275.67	1818.92	Seed production
Cocoa	*Theobroma cacao*		Essential[1]	0.95	171.84	163.25	
Opium(MT)	Papaver *sommniferum*	494.33	Little[1]	0.05	96.16	4.81	
Tea (million Kg)	*Camellia sinensis*	972.23	No increase[2]	0.00	8910.90	0.00	
Tobacco	*Nicotiana tabacum*	0.58	No increase[2]	0.00	8049.24	0.00	
Saffron	*Crocus sativus*		Unknown[3]	0.00	40.4	0.00	
Betel leaves	*Piper betle* L.		Unknown[3]		7470.80	0.00	
Isabgol	*Psyllium* spp.		Unknown[3]		552.17	0.00	
Others			Unknown[3]		9492.80	0.00	
Total drugs and narcotics					42059.98	1986.97	
Increase in production due to animal pollination (%)						4.72	
Pulses (Production million tonnes)							
Major pulses							
Cowpea	*Vigna sinensis* L.	0.017	Little[1]	0.05	0.00	0.00	
Gram, chickpea	*Cicer arietinum* L.	6.52	No increase[1]	0.00	33756.82	0.00	
Lentil, masur	*Lens esculenta* Moench.	0.97	No increase[1]	0.00	3925.10	0.00	
Moong, greengram	*Phaseolus aureus* Roxb., *Vigna huckli* L.	1.24	Little[1]	0.05	5185.88	259.29	
Moth	*Phaseolus aconitifolius* Jacq.	0.34	Little[1]	0.05	2033.86	101.69	
Peas (Garden and field)	*Pisum sativum* L.	0.42	No increase[1]	0.00	2392.75	0.00	
Pigeonpea, arhar, tur	*Cajanus cajan* (L.) Millsp.	2.57	Little[1,3]	0.05	11149.90	557.49	
Rajmash, kidney bean	*Phaseolus vulgaris*	0.07	Little[1]	0.05	0.00	0.00	
Urd, blackgram, mash	*Phaseolus mungo* Roxb.	1.48	Little[1]	0.05	6352.94	317.65	
Other pulses			Unknown[1]	0.00	1444.52	0.00	
Total major pulses					66241.76	1236.13	
Increase in production due to animal pollination (%)						1.87	
Minor pulses							
Broad bean	*Vicia faba* L.		Modest[1]	0.25	0.00	0.00	
Common bean	*Phaseolus vulgaris*		Little[1,2]	0.05	0.00	0.00	
Horse gram, kulthi	*Macrotyloma uniflorium* (Lam.) Verdc.	0.27	Unknown[1]	0.00	497.71	0.00	
Jack bean, sword bean	*Canavalia* spp.		Little[1]	0.05	0.00	0.00	
Kesari, Lythyrus, chickling pea	*Lathyrus sativus* L.	0.38	Unknown[1]	0.00	834.27	0.00	
Rice bean	*Vigna umbellate* (Thunb.)		Unknown[1]	0.00	0.00	0.00	
Sem, Lablab	*Dolichos lablab* L.	0.10	Modest[1]	0.25	0.00	0.00	
Yam bean	*Pachyrrhizus erosus*		Unknown[1]	0.00	0.00	0.00	
Total minor pulses					1331.98	0.00	

Contd.

Table 6 (*Concluded*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Increase in production due to animal pollination (%)						0.00	
Total pulses					66573.75	1236.13	
Increase in production due to animal pollination (%)						1.83	
Other crops (Production 000 tonnes)							
Guar seed*	*Cyamopsis tetragonoloba*	1350.30	Little[1]	0.05	26236.00	1311.80	
Mulberry			Modest[2]	0.25	32.74	8.19	
Fodder			Unknown[1]		33532.42	0.00	
Grass			Unknown[1]		15301.41	0.00	
Rubber	*Hevea brasiliensis*	786.81	No increase[1]	0.00	14675.39	0.00	
Mushroom			No increase[1]		522.18	0.00	
Misc. food crops			Unknown[1]		27.71	0.00	
Misc. non-food crops			Unknown[1]		1447.48	0.00	
By products					70558.49	0.00	
Kitchen garden					5781.92	0.00	
Total of other crops					168115.75	1319.99	
Increase in production due to animal pollination (%)						0.79	

respectively. Niger and *taramira* with great dependence on pollinators had an EVP of ₹ 211.55 and 114.04 crores. Groundnut was the only major oilseed with little insect pollination benefits (up to 10%) but still contributed ₹ 1036.40 crores from its EV of ₹ 20 728 crores. The important non-edible oil producing castor too is moderately benefitted by insect pollination, contributing a significant ₹ 2223.58 crores to its output value.

Non oilseed crops also are a formidable contributor to this segment. Cottonseed, a by-product of cotton lint production is the source of high quality edible oil while the left-over seed cake is used as animal feed. Cotton is modestly benefitted by insect pollination, increasing lint production as well as the number of seeds/boll and eventually the production of cottonseed oil. From a production of cottonseed at 7.37 million tonnes (Agarwal and Gopalakrishnan 2007) valued at ₹ 12 968.00 crores, the contribution of animal pollination is estimated at ₹ 3 242.0 crores. Soybean being an important pulse crop is mainly grown for edible oil and thus, included in oilseeds (not in pulses). Insect pollination result in modest increase in yield and contributes ₹ 12 528.72 crores towards total soybean output value of ₹ 50 114.90 crores. Coconut too has modest bearing on yield due to insect pollination that signifies into ₹ 2 817.38 crores of its total output value of ₹ 11269.53 crores.

Besides individual variations in insect pollination benefits (great to modest) in different crops, oilseeds as a category, is highly dependent on this input for its production and quality improvement. An astonishing average contribution to the tune of 34.1% in yield, valued at ₹ 43 993.08 crores is testimony to this fact (Table 6). Nine major oilseeds together account for an EVP of ₹ 43 609.18 crores (98.8%) with an average yield increase of 34.2%. Rest of the six minor ones contributed only ₹ 383.89 crores, explaining for 24.4% yield increase by insect pollination. Groundnut is the only major oilseed crop with little benefit of insect pollination but still contributes ₹ 1 036.40 crores of its total output.

Fruits: Fruits are hugely important source of quality human nutrition especially sugars, vitamins, minerals, etc. besides export earners of the country. Their contribution to Indian agriculture (Table 6) is vital and ranked fifth in terms of output value at ₹ 129 030.05 crores (10.0%). Majority of fruits are consumed in their vegetative stages (fresh) thus, sometimes real visual animal pollination benefits alludes except increased fruit set. Successful optimum pollination and consequent fertilization, through hormones, stimulates tissue proliferation around ovaries leading to the development of proper shaped fruits. Lack of pollination/fertilization thus, results in ovary abortion and leads to the development of misshapen fruits. The major loss in horticultural production is from these misshapen or deformed fruits that are either unmarketable (rejects) or fetch very low prices (B, C or D grade). It is never realized that lack of pollination is the root cause of this huge loss of marketable produce. The other benefits of pollination accrue in other forms like increase in seed production, breeding efficiency, etc.

Fruits are one of the largest groups, but for this study, only 55 fruits were selected that include 27 major and 28 minor and it excluded floriculture and medicinal plants (Table 2, 6). Fruits as a segment are benefitted significantly by animal pollination in terms of increased production. The importance of animal pollinators can be gauged from the fact that two third (41) fruits need insect pollination for

their production while only 4 (7.3%) are not dependent while for 10 (18.2%), the information is not available. This fact is further reinforced as 3 fruits (5.5%) entirely depend on insect pollination (in its absence 90-100% reduction in production occurs), 20 greatly dependent (36.4%) and for 9 each (16.4%) dependence was moderate and low, respectively.

Considering individual fruits for their economic value of pollination (EVP) revealed their amplified dependence on pollinators for fruit set (Table 6). Apple with an average production of 1835.9 MT and economic value of ₹ 5 577.16 crores is the most benefitted from animal pollination. The estimated economic value of pollination is a whopping ₹ 3 625.15 crores (DR=0.65, 40-90% reduction in yield in absence of pollination). Cashew nut, a very high value cash fruit too is greatly benefitted by bee pollination (DR=0.65) and is the second largest contributor of EVP at ₹ 3 483.87 crores out of the total EV of ₹ 5 359.79 crores.

Oranges though modest in response to animal pollination (DR=0.25), but still ₹ 2 332.67 crores is their contribution from total EV of ₹ 9 330.67 crores. Mosambi (sweet lime) although with relatively lower EV of ₹ 3 464.16 crores but its response to animal pollination is great (DR=0.65) at ₹ 2 251.70 crores. Lemon and other citrus fruits however, exhibit little dependence on pollinators at ₹ 245.65 and 35.82 crores, respectively.

In guava, with great dependence, the contribution of bee pollination is estimated at ₹ 1 858.31 crores (EV= ₹ 2858.93 crores). Contribution of animal pollination in mango production is little (₹ 1 775.74 crores), largely attributed to Indian hive bee, *A. cerana* and many species of flies, mainly in central and South India. Litchi was ranked 7th in terms of EVP (₹ 764.22 crores) with a modest response while pear followed it with great response at ₹ 447.37 crores. Papaya is little dependent on pollinators with an EVP of ₹ 190.42 crores. Almond, mainly grown in Jammu and Kashmir on poor and discarded soils, depends greatly on pollinators with EVP of ₹ 84.55 crores out of a total EV of ₹ 130.08 crores. Among the 28 minor fruits, pollination response of only cherry is available which was greatly dependent on pollinators with an EVP of ₹ 46.82 crores out of the EV of ₹ 72.03 crores. Even for the most voluminous insect pollination unresponsive fruit banana (22.17%) is indirectly benefitted by increase in breeding efficiency.

Major fruits (26 fruits and 1 commodity) cumulatively represent 89.43% of total output value (₹ 115 388.72 crores) but explains 99.72% of animal pollination dependence. Economic value of insect pollination is estimated at ₹ 17 095.45 crores or 14.82 per cent of total economic value of fruits. These benefits are credited to 12 major fruits (44.44%) only (apple, almond, cashew nut, lemon, mosambi, orange, guava, litchi, mango, papaya, pear and a commodity representing other citrus fruits). Such values for 15 fruits (44.5%) were not known and 3 fruits (11.1%) did not depend on insect pollination.

On the contrary, for 28 minor fruits (including 3 commodities) valued at ₹ 13 641.33 crores, animal pollination dependence for ₹ 46.82 crores only (0.34%) has been accounted that too for lone fruit (cherry) as for the rest, such information is lacking. Insect pollination dependence scenario was almost similar to major fruits with 75.0 per cent fruits needing animal pollination and only 1 (3.6%) fruit was independent, while for 6 (21.4%) the data was not available. Among the insect pollinated fruits, the dependence for one (3.6%) was essential, great for majority (11, 39.3%), 5 (17.9%) moderately and low for 4 (14.3%).

Considering overall scenario for fruits, economic value of insect pollination service was estimated at ₹ 17 142.27 crores representing 13.29% of the total output value of fruits. It is a pity that insect pollination values are available for only 29.1 per cent (16) fruits) that comprised of 15 major fruits but regretfully, only one for minor fruits. With the availability of further data for 70.9 per cent fruits, the scenario is likely to change significantly for their pollination dependence. The major benefit of pollinators is the quality gain in fruits.

Floriculture has recently developed as an important field with a value of ₹ 19 193.83 crores and their value of pollination remains to be properly explored but many of these flowers depend on insects for setting seed and similar is the fate of medicinal plants.

Vegetables: Vegetables as a group are the third largest contributors to Indian agriculture (13.61%, ₹ 175 777.81 crores). Like fruits, majority of vegetables are consumed fresh, alluding apparent bee pollination benefits, as explained earlier. For this study, 50 vegetables, 25 each from major and minor group were included (Table 2, 6). Among the 38.0% vegetables (19) needing insect pollination for their production, dependence of 7 (14.0%) was essential while of 2 (4.0%) was great, modest and little for 5 (10.0%) each, respectively for this vital input. Forty two per cent (21) vegetables were not dependent on animal pollination while such contribution for 20% (10) is yet to be ascertained. Of the 11 major pollination dependent vegetables, 4 (16.0%) especially cucurbits (bottle gourd, bitter gourd, pumpkin, squash, etc.) and custard apple were essentially dependent on insect pollination as in their absence 90-100% reduction in yield was witnessed, but for want of data, their EVP could not be estimated.

Two vegetables greatly benefitted by bee pollination (DR=0.65) are tomato and cucumber. Economic value of pollination in tomato is estimated to the huge amount of ₹ 11977.90 crores from its total EV of ₹ 18427.54 crores, while for cucumber such information is lagging. Brinjal was modest in pollinator dependence (DR=0.25) with an estimated value of ₹ 4841.97 crores from an EV of ₹ 19367.90 crores. The second such crop okra benefitted by ₹ 2603.48 crores from pollinator service out of its total economic value of ₹ 10413.94 crores. Although 3 vegetables (beans, peppers and sweet potato) had little dependence on pollinators, but EVP was estimated only from sweet potato at ₹ 74.84 crores. For jackfruit (₹ 1654.21 crores) and commodity – other vegetables (a group of many minor

vegetables) valued at staggering ₹ 39 159.60 crores, animal pollination dependence still needs to be determined.

Twelve (48.0%) major vegetables do not require insect pollination (potato, cabbage, cauliflower, carrot, onion, peas, arbi, radish, spinach, tapioca, turnip, roots and tubers) and their cumulative value is a whopping ₹ 85 214.55 crores. However, even among these, barring peas, arbi, tapioca, roots and tubers, rest of the vegetables were benefitted in more than one ways by pollinators like increased seed production (cabbage, cauliflower, carrot, onion, radish, spinach, turnip) or improved breeding efficiency (potato).

Surprisingly, for 25 minor vegetables, the crop product value is available for only one crop namely drumstick (₹ 43.35 crores) but its economic value of insect pollination service could not be ascertained. Three (12.0%) vegetables essentially required insect pollination service while for equal numbers, the value was modest and for 2 (8.0%) was little. Nine vegetables (36.0%) were independent of such insect pollination input and for 8 (32.0%), it was yet to be assessed.

Despite all these huge information gaps, economic value of insect pollination from vegetables was estimated at ₹ 19 498.20 crores annually or 11.09% of total value of vegetables. As explained for fruits earlier, the immense quality benefits exist for majority of vegetables also. Unfortunately, the situation on available pollination aspect is pathetic and with the generation of systematic information, the EVP is bound to shoot up significantly.

Fiber crops: Fibers contribute 5.72 per cent (₹ 73 917.05 crores) to the total agricultural output of the country (Table 2, 6) and cotton is the major fiber crop contributing 93.5% of total fibers, followed by jute (6.14%). Cotton is a highly entomophilous crop, visited for its attractive floral and extra-floral nectar. Consequently, contribution of insect pollination is modest (DR=0.25, in absence reduction of 10-40% in yield) for its lint production, estimated at a massive value of ₹ 17 279.79 crores annually from its total economic value of output of ₹ 69 119.16 crores. Sann hemp though a minor crop, also has modest pollination dependence but with a meagre share of ₹ 10.87 crores. Jute and mesta are not benefitted by insect pollination. Cotton and sannhemp's contribution accounts for 23.39% increase in EVP (₹ 17 290.66 crores) of all the fibers.

Cotton with copious extra-floral and floral nectar of high sugar concentration is a major potential honey crop in India. In addition to the improvement of lint yield, insect pollination also increases boll size, seed germination and number of seeds/boll (Free 1993, Rhodes 2002, Kaziev 1961, McGregor 1955). Cottonseed produced as a byproduct, yields valuable edible oil and has been dealt separately under oilseeds.

Condiments and spices: Small cardamom essentially required insect pollinators (DR=0.95) for capsule production and these gains were expressed in its EVP that was valued at ₹ 1 104.70 crores (EV ₹ 1 162.85). Cumin seed production was greatly attributed by animal pollinators (DR=0.65) reflecting in ₹ 4 029.22 crores value of pollination. Coriander too was similarly benefitted to the tune of ₹ 1 549.79 crores. Nutmeg and fennel with EVP of ₹ 275.98 and 232.17 crores, respectively were also greatly dependent on pollinators. Benefit of insect pollination in these 4 spices amounted to ₹ 6 087.85 crores from their total economic value of ₹ 9 364.85 crores. EVP of celery with great dependence on pollinators could not be ascertained for want of data on its EV. Chilli, the spice with most economic value of output (₹ 10081.00 crores) was modest in its response to pollinators (DR=0.25) but still ₹ 2 520.25 crores was attributed by this precious input. The little pollinator benefitted spices, viz. arecanut, chilli pepper and tamarind had insect pollination component of ₹ 397.32 crores.

Two of the 8 minor spices were essentially dependent (dil and vanilla) on animal pollination while 2 greatly (allspice and anise) and 1 modestly benefitted in their production. Only 2 spices did not require animal pollination and such contribution was unknown for 3 spices. However, the data on economic value individually, is not available thus, for all the minor spices valued at ₹ 2055.15 crores economic value of pollination could not be ascertained.

The economic value of insect pollination in major condiments and spices thus, was estimated at ₹ 10 121.19 crores, accounting for 26.90% of their total output value of ₹ 37 629.42 crores. Overall, insect pollination contributed 25.50% of their EV of ₹ 39 684.57 crores.

Drugs and narcotics: These crops also known as stimulants contribute 3.26% to the total Indian agriculture with an output value of ₹ 42 059.98 crores (Table 2, 6). Coffee (green beans) requires modest animal pollination services (DR=0.25) and contributed ₹ 1 818.92 crores to its total economic value of ₹ 7 275.67 crores. Cocoa however, essentially needs pollinators, resulting in ₹ 163.25 crores contribution. Quality of both coffee and cocoa is governed by quality of their berries/seeds which in turn is governed by insect pollination. For opium, animal pollination is of little significance but still contributed ₹ 4.81 crores to its total EV. A huge chunk of crops including beetle leaf, *isabgol*, saffron and the commodity "other drugs and narcotics" accounting for ₹ 17 556.17 crores (41.74%), remained unexplored for their animal pollination dependence. However, two major crops - tea and tobacco- with a combined output of ₹ 16 960.14 crores reflected no decrease in yield in absence of animal pollinators. Share of insect pollination in the production of drugs and narcotics though seems small at ₹ 1 986.97 crores (4.72%) in absence of lack of studies, but is highly significant for improving the quality of coffee and cocoa berries.

Pulses: Of the 10 major pulses, six are benefitted by animal pollinators to little (DR=0.05) extent. Pigeon-pea with a production of 2.57 MT and economic value of output of ₹ 11 149.90 crores, even with little contribution of insect pollinators resulted in EVP of ₹ 557.49 crores. Similar contributions for urd, moong and moth are ₹ 317.65, 259.29 and 101.69 crores, respectively. In these four pulses, contribution of insect pollinators as EVP is ₹ 1 236.13 crores. Such values for cowpea and rajmash could not be estimated for want of information on their EV. Gram, the

largest pulse, is not benefitted by insect pollinators and so is the case with lentil and peas (both garden and field). Considering the minor pulses (8), attribution of insect pollinators in yield was modest (DR=0.25, 10-25% yield reduction in pollinator's absence) in broad bean and sem, little in common bean and jack bean, while for rest of four, information was not available. Pollination value for any of minor pulses could not be estimated for want of data either on product value or dependence rate.

EVP information lag (availability of 4 out of 15) and predominant self pollination breeding systems in pulses inherently make this category as little to modest responsive to the input of animal pollination although many specialized mutualistic associations has been recorded. The estimated EVP of ₹ 1236.13 crores signifies merely 1.87% of total EV of pulses but has potential of upsurge.

Indigo and dyes: The indigo plant needs heavy-bodied insects to jerk-open the flowers to effect pollination and at modest pollination dependence (25% increase) contribute ₹ 27.25 crores from the total output value of ₹ 109.00 crores (Table 6).

Sugars: Sugar producing crops like sugarcane and sugar beet are not benefitted by animal pollination though latter's seed production is increased by insect pollination. This major category worth ₹ 80 971.92 crores (6.27% contribution to national output) thus, is unresponsive to pollinators (Table 6).

Other crops: This group consists of diverse crops and commodities not covered anywhere and have substantial contribution of 14.21% (₹ 238 674.24 crores) to total agriculture output of the country (Table 2, 6). Guar though little benefitted, accounts for ₹ 1 311.80 crores worth of insect pollination benefits (from EV of ₹ 26 236.00 crores) while mulberry at modest level gains ₹ 8.19 only.

Fodder crops mainly berseem (Jat *et al.* 2014) and lucerne are highly entomophilous, absolutely requiring insect pollination for seed production and quality improvement. Miscellaneous food and non food crops, fodder and majority of kitchen garden crops valued at ₹ 40 789.53 crores need pollination for their production and survival but precise information is not available due to smaller acreage, low economic value or isolated cultivation. Four crops/categories (rubber, mushroom, grass, by-products including straw and stalks) did not benefit by animal pollination and account for the major chunk of ₹ 101 057.48 crores.

Presence of such a huge gap in information thus, prevented to estimate the economic value of pollination in this category but it could be safely assumed that a far significant proportion is attributed to insect pollination than the presently estimated ₹ 1319.99 crores or 0.79%.

Contribution of different agencies in affecting crop pollination: Amongst a host of agencies reported as crop pollinators, the data provided a crystal clear picture of overwhelming dominance of insect pollinators to the tune of 97.4% in crops under review. Birds, mainly humming birds (1.7%) and bats (1.0%) were the other animals contributing to the pollination of their specially co-evolved hosts. The contribution of bees (79.2%) as pollinators was vivid, overwhelmed by the honey bees (40.6%) and further from solitary (21.1%) and bumble bees (13.5%). Flies from order Diptera (9.6%) also contributed significantly.

Information gaps: In India, the overall insect pollination scenario is extremely pathetic in terms of research activities and availability of information. Research gap apparently exists for 20.9% (44 numbers) of crops marked unknown, but the list may actually become quite extensive as 19 of them are commodities (aggregates of crops). The value of this unknown segment is whopping ₹ 228 533.15 crores. Barring few, Indian studies typically lack standard protocols to stand rigorous international scientific scrutiny. Moreover, data for most of the animal pollinated crops is based on foreign studies and it is a common knowledge that plant-pollinator interactions depend on many factors including variety (soybean, apple, etc.), geography, management practices, etc. In Brazil, Giannini *et al.* (2015) confirmed variable response of cultivars to pollinators in soybean, some exhibiting modest while others have little dependence. Data availability is the second concern, as out of 211 crops studied, the economic value is not available for 92 (43.6%) crops (including 2 commodities). The biggest causalities were minor crops (64, 30.33%) while for 26 major crops (12.3%) also, the values were not available. Even among the animal pollinated crops (108), EV was missing for 57 (52.8%) crops (19 major and 38 minor). Low acreage/ economic value, regional importance, grouping of minor crops into commodities, reporting mechanism, etc. are the major reasons of the lacunae.

Economic value of animal pollination in India: Even with this fragmented information, major evidence of direct contribution of animal pollination in 108 entomophilous crops (51.2%) exists and economic value of pollination (EVP) to Indian agriculture has been estimated at a staggering ₹ 112 615.73 crores (8.72%) annually (Table 7). Animal pollinated crops (Table 3) comprise 31.76% (₹ 410 094.77 crores) of the total economic value of output (EV) of Indian agriculture (₹ 1291 369.63 crores at 2012-13 prices). Both these values (EVP and total value of animal pollinated crops) are likely to be substantially higher once results from systematic planned pollination studies from Indian specific crops are available and information flow gaps are plugged. The number of non-pollinator dependent crops although was small (28.0%) but these 59 crops represent 50.55% of total national EV (₹ 652 742.12 crores) and comprised mainly of cereals and other parthenocarpic crops.

Present study is the world's largest in scale, involving 211 Indian crops (190 crops and 21 commodities) compared to only 124 (57 leading single and 67 leading commodity crops) classified globally by Klein *et al*. (2007), 100 (89 crops and 11 commodities) by Gallai *et al.* (2008) and 141 by Giannini *et al.* (2015). In India, 108 (51.2%) crops were observed to be pollinator dependent and 59 (28.0%) non-dependent. However, at global level, Klein *et al*. (2007) and Giannini *et al.* (2015) recorded a higher (70.0 and 60.28%, respectively) but Gallai *et al.* (2008) a

Table 7 Economic value of animal pollination services to Indian agriculture

Crops / Commodities	Crop product value (₹ crores) at current prices (EV)	Proportion to total value of output from agriculture (%)	Economic value of pollination (EVP) (₹ crores)	Increase due to animal pollination (%)
Cereals	365 793.00	28.33	0.00	0.00
Oilseeds	129 143.00	10.00	43 993.08	34.07
Fruits	129 030.05	9.99	17 142.27	13.29
Floriculture	19 193.83	1.49	0.00	0.00
Vegetables	175 777.81	13.61	1 9498.20	11.09
Fibers	73 917.05	5.72	17 290.66	23.39
Condiments and spices	39 684.57	3.07	10 121.19	25.47
Drugs and narcotics	42 059.98	3.26	1 986.97	4.72
Pulses	67 574.00	5.23	1 236.13	1.83
Indigo and dyes	109.00	0.01	27.25	25.00
Sugars	80 971.92	6.27	0.00	0.00
Other crops	168 115.75	13.02	1 319.99	0.79
Grand total	12 91 369.63		112 615.73	
Contribution of animal pollination (%)			8.72	

lower (46.0%) proportion of pollination dependent crops. For non pollinator dependent crops, the values reported varied from almost similar (28, 24.35%) by Klein *et al.* (2007) to significantly higher (43) by Gallai *et al.* (2008). Such estimates for crop's dependence - purely on breeding systems and without pollination studies- for 264 European crops were put at 84.0% by Williams (1994).

Segregating further these crops, based on degree of insect pollination dependence (Table 4), 29 crops with modest dependence (DR=0.25, yield reduction of 10.0-40.0% resulted in their absence) recorded EV of ₹ 221 956.48 crores and for 31 crops with little dependence (DR=0.05, up to 10.0% reduction), value was ₹ 127 135.24 crores. The 34 crops with great dependence (DR=0.65, reduction of 40-90%) had an EV of ₹ 72636.37 crores while such value for 14 essentially dependent crops (DR=0.95, reduction of 90-100%) was only ₹ 1 334.68 crores. Considering these values on the basis of dependence rate or actual contribution of pollinators in yield (or reduction in their absence), termed as economic value of pollination (EVP), contribution of modest and great pollinator dependent crops was maximum at ₹ 54 149.17 and 50 697.50 crores, respectively while such values for little and essential category were ₹ 6 501.10 and ₹ 1 267.95 crores, respectively. Among the 107 crops evaluated by Klein *et al*. (2007), animal pollination was reported to be essential for 13, great for 30, modest for 27 and little for 21 crops in their production, whereas this proportion as reported by Gallai *et al.* (2008) was 6, 13, 13, 14, respectively for 100 crops, confirming present results of fewer crops with essential pollinator dependence.

Important animal pollination dependent crops requiring special attention: Rapeseed and mustard is the most important oilseed crop in the country dependent greatly on the inputs of animal pollination (in their absence 65% reduction in yield occurs) with an estimated EVP at ₹ 19 355.70 crores. Around 26-34% area is under rainfed cultivation that if brought under irrigation has potential to double seed yield (Anonymous 2015 b). Mustard is a standalone crop and could act as a classical case study of bee pollination benefits for tremendous national gains.

The economic value of pollination of cotton as a lint yielder (₹ 17 279.79 crores) as well as cottonseed producer is aggregated at ₹ 20 521.79 crores besides increase in quality parameters (Free 1993, Rhodes 2002, Kaziev 1961, McGregor 1955). The flip side is that cotton is infested with large number of insect-pests and credited with almost 50% of total insecticide consumption of India, making it a dreadful crop for natural enemies and pollinators. Availability of effective IPM options with least pesticide load are available but their altogether lack of field implementation puts a question mark on one of the most resource rich crop. Mass application of neonicotinoid insecticides-mainly imidacloprid- on cotton in India that has a history of fatal effects on honey bees even at sub-lethal doses and has been banned in the European Union (EU 2013) is another serious concern. Soybean (a source of edible oil) with modest dependence on pollinators contributes ₹ 12 528.72 crores towards its EVP, although pollination dependence is variety specific as reported by Giannini *et al.* (2015).

Other oilseeds, viz. coconut, sunflower, sesamum and groundnut too were estimated with higher EVP of ₹ 2 817.38, 1153.40, 1071.58 and 1036.40 crores, respectively. The non-edible castor too pitches in with an EVP of ₹ 2223.58 crores. Besides yield increment, pollination is also reported to significantly improve quality of oilseeds (Free 1993). In rapeseed and mustard, bee pollination resulted in higher number of bolder seeds besides early and uniform crop maturity (Adegas and Noqueira Couto 1992, Abel and Wilson 1999, Morandin and Winston 2005). In sunflower, higher seed weight with increased oil content and

germination was reported (Wakhle *et al.* 1978, Greenleaf and Kremen 2006, Aslan and Yavuksuz 2010). Similar increase in qualitative parameters has also been reported in other oilseeds like sesamum (Mahmoud 2012), coconut (Da Conceicao *et al.* 2004, Melendez-Ramirez *et al.* 2004), etc.

India is chronically highly deficient in oilseed production, despite oilseed mission and other special value inputs by the government (Anon. 2014). Oilseeds with 13.9% of gross cropped area and an average annual production of 22.21 MT are mired with low productivity owing to their cultivation in rainfed or marginal soils and are unable to fulfil demand (Anon. 2015 b). This great void in demand and supply is met through huge imports to the tune of 14.5 million tonnes valued at $10.5 billion or nearly ₹ 70 000 crores in 2014-15 (Anon. 2015 f), mainly of lower quality oil palm, soybean oil and canola oil. In contrast, annual gains due to bee pollination in oilseed segment are pegged at ₹ 43 993.08 crores even at average yield (of last 14 years) at current prices. There exist enormous scope and urgent need to increase production and productivity of oilseeds by undertaking specific pollination intervention in mission-mode program that has potential not only to wipe out this deficit but save precious foreign exchange and other associated benefits.

Apple is the most benefitted fruit in terms of EVP of ₹ 3 625.15 crores. The orchardists of Himachal Pradesh has realised the obligate necessity of honey bees in pollinating, fruit production and quality gains of apple (Sharma and Pratap 2012). Many of them have adopted placing honey bee colonies in their orchards during flowering, as a standard package of practices. As a token of this service, they are paying rentals to the beekeepers for hiring honey bee colonies at a rate of ₹ 1000-1200/colony. It is the first case of commercial need-oriented pollination service in India (Chaudhary 2014). Similar but isolated endeavours have been reported from few horticultural crops (pomegranate, etc.) in states like Maharashtra. Cashew nut closely follows apple in terms of EVP at ₹ 3 483.87 crores due to very high product price even though it's miniscule in production volume. Reaction of citrus fruits is variable to the input of bee pollination. Oranges are modest, mosambi (sweet lime) great, lemon and other citrus fruits are little dependent but still has a significant EVP of ₹ 2 332.67, 3 464.16, 245.65 and 35.82 crores, respectively. Guava, litchi and pear with great to modest pollination needs were benefitted to the tune of ₹ 1 858.31, 764.22 and 447.37 crores while such values for mango and papaya are ₹ 1 775.74 and 190.42 crores. Mango inflorescence is pollinated by smaller sized pollinators especially hover flies, *A. cerana* and *A. florea*.

Although almond greatly requires bee pollination but its EVP is low (₹ 84.55 crores) due primarily to very low productivity for being frown in marginal soils in J&K and absolute lack of bee pollination initiative. This situation is in stark contrast to USA that produces more than 80% of the world's exportable almonds, entirely dependent on honey bee pollination. Country's 75% of 2.5 million bee colonies are migrated to almond state of California in February by the beekeepers, which enter into a legal agreement with orchardists for this service at a rental price of about US$ 180/ hive. Colony rentals are up from $ 6-9 in 1970's only on the realization that bee pollination is essential for the almond production and in its absence, yields will be drastically reduced. In 2016, around 2 million colonies are expected to produce 2 billion pounds of almonds (USDA 2016)

Besides such huge quantitative gains, fruits are greatly benefitted in terms of quality parameters by insect pollination in terms of increased size, uniform shape (lack of deformities), taste, sweetness, increased number of seed/achenes, etc. A well pollinated crop will have less malformed or inferior quality fruits as in case of strawberry, where percentage of nubbins (B-quality malformed fruits) decreased from 29.0 (in without pollination) to 6.0% (in bee pollination), adding an additional 23% high quality (A-grade) berries to marketable yield (Nagar and Chaudhary 2006). Such traits are essential for export as well as domestic consumption but are never taken into account while calculating EVP.

Among vegetables, tomato with great dependence on animal pollinators has an estimated EVP of ₹ 11 977.90 crores. Many marketable variants of tomato (cherry tomato, etc.) are being increasingly grown under protected cultivation (poly houses) where the pollination especially by bumble bees is employed in temperate world and is defined as the major bottleneck of low productivity. In absence of bumble bees, mechanical vibrators are being used to perform the function of honey bees. Three other important vegetables namely, brinjal, chillies and okra with modest pollinator dependence contribute ₹ 4 841.97, 2 603.48 and 2 520.25 crores as their respective EVP. All these vegetables are however, subjected to huge pesticide pressure to ward off insect-pests and diseases. The sorry state is their use (rather misuse) through regimented treatment schedules, without following basic IPM principles (economic thresholds, choice of insecticides, waiting period, etc.) that are detrimental to their biological control agents/natural enemies and also to the pollinators.

Important spices dependent on animal pollinators were cumin (EVP ₹ 4 029.22 crores), chilli (₹ 2 520.25 crores), coriander (₹ 1 549.79 crores) and cardamom (₹ 1104.70 crores). Other spices although greatly depended on pollinators but lower EV resulted in lower EVP of ₹ 275.98 crores (nutmeg), 265.58 (arecanut), 232.17 (fennel), 211.55 (niger seed) and 91.84 (black pepper). Stimulant crop coffee is modest in response to pollinators while for cocoa it is essential with a contribution of ₹ 1 818.92 and 163.25 crores, respectively. Guar seed with little dependence still had an EVP of ₹ 1 311.80 crores.

Pulses being self pollinated respond little to animal pollinators but their large acreage result in reasonable EVP benefits of ₹ 557.49 (pigeonpea), 317.65 (urd), 259.29 (moong) and ₹ 101.69 crores in moth bean. India is a hugely pulse deficient country with an annual import accounting for 16.36% of demand and government proposes to increase pulse production through area increase and technology

intervention. During 2012-13, India imported 3 837.56 thousand tonnes of pulses worth ₹ 12 738.64 crores while average value of pulses output in India from 2000-01 to 2013-14 was ₹ 67 573.75 crores (Anon. 2015 f). Against a mean demand of 18.31 million tonnes and a supply of 16.27 MT, a supply gap of 2.04 MT (11.1%) existed (www.indiaagristat.com). With a potential to increase up to 10% yield in many pulses, planned pollination could play significant role in reducing this demand gap.

Needless to say, it is utmost important to usher in the dedicated planned pollination initiatives in these crops to harness their real productivity and qualitative benefits for food safety and nutrition requirement of Indian populace.

Important categories of crops needing urgent attention: Oilseeds as a category with 34.1% contribution from animal pollination valued at ₹ 43 993.08 crores annually (Table 7) is the single largest category of crops with quantitative and qualitative benefits. Fulfilment of optimum and even escalated saturated pollination needs of these crops has the potential of significant incremental quantitative and qualitative benefits, going far beyond the estimated EVP. National mission on oilseed and oil palm (NMOOP) projected vegetable oil demand for the country at 20.4 million tonnes by 2017 (Anon. 2015 f, Anon. 2014, http://nmoop.gov.in) and suggested various components through three mini missions to achieve them but surprisingly, planned honey bee pollination does not find any mention in the scheme of things part! Such an integral approach could greatly help in mitigating the chronic deficiency of oilseeds in India.

Fruits (13.29%, ₹ 17 142.27 crores), fibers (23.39%, ₹ 17 290.66 crores), condiments and spices (25.47%, ₹ 10 109.43 crores) and vegetables (11.09%, ₹ 19 498.20 crores) are the other major categories with immense contributors to Indian agriculture besides poorly explored pulses and other crops. So, except cereals and sugars, all the other categories are directly benefitted by insect pollination, though indirect benefits through increased seed production, improving efficiency of breeding system are also accruable to non-pollinated categories and crops. Such contributions of animal pollination has also been reported by many workers with varied values (Klein *et al*. 2007, Gallai *et al.* 2008, Giannini *et al.* 2015) further confirm the dependence of crops on bee pollination.

NITI Ayog (Anon. 2015 b) in order to raise agricultural productivity has strongly recommended a significant shift into high value commodities like fruits, vegetables, etc. and these segments are one of the most dependent on animal pollinators for their production and quality. In light of the above findings, it is suggested that special pollination missions in different crops and commodities are immediately initiated with thorough integration of planned pollination through honey bees and other wild bees/pollinators, a strategy that has till now eluded the planners framework.

Frequency of pollinating agents in different crops: Results indicate that the term animal pollination being preferably used in scientific parleys may actually be interchangeably used or even replaced with "insect pollination" as in 97.4% of the case studies, insects constituted the pollinating agents. They far outstripped other animals in terms of numbers (2) as well as proportion (2.7%). In 79.2% cases, bees actually performed this important function thus, appropriately referred to as "bee pollination" also. Such a conclusion still grossly under rates the value of honey bees with specially adopted morphological features especially floral consistency, fidelity, plumose body, feeding habit, etc. and co-evolution with angiosperms (flowering plants), were referred to be as the perfect pollinators by Free (1993). Presence of other unmanaged floral visitors even in large numbers is no guarantee of pollination owing to their poor pollination efficiency. Planned bee pollination from managed hives is an added advantage in situations of low availability of natural pollinators or their destruction due to habitat destruction or pesticide toxicity.

Pollination cycles requirement: For optimum yield realization of animal pollinator dependent crops, honey bee colony requirement per unit area has been worked out that varies from crop to crop depending upon their density, number of flowers, etc. For rapeseed and mustard, 5 *A. mellifera* colonies are required/ha. In a case study, Chaudhary (2014) estimated that for mustard crop alone, grown in 548 000 ha in Haryana, 27.4 lakh pollination cycles or colonies are required for optimum yield against the maximum availability of about 1.0 lakh colonies. There are many more crops like sunflower, *berseem*, cotton, fruits, vegetables, etc. requiring these essential services. There is thus, a huge gap (96.35%) in the requirement and availability of honey bee colonies thus, preventing the realization of production potential of the crop. Similar situation exists for large cache of entomophilous crops in India due to availability of a mere 13 lakh colonies.

Contribution of animal pollination to Indian agriculture: Even with these huge knowledge gaps, direct contribution of insect pollination to Indian agriculture is staggering, at ₹ 112 615.73 crores or US $ 22.52 billion (@₹ 50/ dollar of 2012-13 base), representing 8.72% of total value of agriculture, annually. Indian agriculture is valued at ₹ 12 91 369.63 crores at 2012-13 current prices (USD 258.27 billions) and the total value of animal pollinated crops is estimated at ₹ 422 827.52 crores (USD 84.57 billions) or 32.74% of total value (EV). Both these values (EVP and total value of animal pollinated crops) can be substantially higher once systematic planned pollination studies reveal results of Indian specific crops. Chaudhary (2014) while analyzing the constraints of Indian beekeeping, reported honey bees having direct bearing on production of crops sown in 48.5% area. With present number of domesticated honey bee colonies (1.3 million), he estimated that 98.3% of the beekeeping potential still remains unexplored. So, once optimum pollination needs of the crops are met, the present yield levels are set to increase and so will be the bee's pollination contribution to Indian agriculture. Additionally, these quantitative benefits are associated with substantial spill over benefits and tremendous increase in quality traits,

besides ecosystem services, which is beyond the purview of the present study.

Almost similar trend was recorded at global level where EVP was estimated at 9.5% amounting to €153 billion, out of the value of the world agricultural production (€1618 trillion) used for human food in year 2005 (Gallai *et al*. 2009). The value of insect pollinated crops was €625 billion or 39.0% of world crop values. The economic benefits were highest in vegetables followed by fruits and edible oils while negligible in sugars, cereals and root and tubers (Klein *et al*. 2007, Gallai *et al*. 2009). Giannini *et al*. (2015) also estimated the contribution of pollinators in Brazil at US$ 12 billion (about 30%) from total value of crops at $ 45 billion, half of it coming from soybean ($ 5.7 billion) alone. However, in present studies the contributors in order of importance were oilseeds, fruits, fibers, vegetables and spices in strike contrast to the world trend.

Future strategies: Authors suggest three pronged strategies for improving the crop productivity and quality: i) Optimum, rather saturated utilization of animal pollination (bee pollination) inputs for the existing entomophilous crops, and ii) Crop diversification to high value commodities like fruits, vegetable and oilseeds that are generally entomophilous, iii) Increasing profitability of beekeeping enterprise.

Annual economic value of insect pollination primarily from honey bees, at ₹ 112 615.73 crores from a miniscule beekeeping sector, pegged at ₹ 385.7 crores at 2014 year base value (Chaudhary 2014) may provide some interesting thoughts to the policy planners. It is especially true in the face of alarming level of food and non-food subsidy provided by the government on mainly non-productive (oilseed and pulses subsidy, MSP) and rather retarding inputs (agrochemicals) that ultimately have retro gradable impacts. It is especially true in face of dire threats to the honey bees and pollinators from insecticides (Goulson 2013) in general (particularly neonicotinoids, now banned in European Union, EU No. 485/2013) and habitat loss (50% pollinator decline in USA and 40% in India), since such losses have been linked to agriculture production decline world over. Such losses has forced US president to order a decree to conserve honey bees and other pollinators (Presidential Memorandum, USA 2014), and start of several global initiatives including FAO's Global Action on Pollination Services for Sustainable Agriculture (FAO 2000), Global Pollination Project, Integrated Crop Pollination Project (2014) as well as regional ones to ensure food security and human livelihoods besides preventing the collapse of ecosystem.

As mentioned earlier, Indian agriculture mired with challenges on production front, increased production cost, host of other ills and with no second green revolution in sight besides great technological inputs, needs such "micro concepts" with "macro-economic" impacts. These tiny "honey bees" have the potential to revitalize Indian agriculture at almost negligible cost. There is however, urgent need to understand the potential of this segment and formulate crop/commodity specific strategies under the mission mode.

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