Prospects of Apicultural Entrepreneurship in Coastal Districts of Eastern India: A Melissopalynological Evaluation

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Abstract

A melissopalynological analysis of fifty-one natural honey samples (twenty four spring, fifteen summer and twelve winter) collected during 2010–2011 from two east-coastal districts (20°20′ to 22°11′ N, 82°39′ to 87°01′ E) of Orissa, India was performed. Out of 37 unifloral samples found 25 were contributed by *Apis cerana indica*, seven by *A. dorsata* and the remaining five by *A. florea*. Out of 14 multifloral samples five were contributed by *A. cerana indica*, five by *A. dorsata* and the remaining four by *A. florea*. Principal component analysis confirmed the palynological classification of the unifloral honey samples. Eighty-two bee-plant taxa belonging to forty four families were recovered. The predominant nectariferous taxa of the spring season were *Acanthus ilicifolius*, *Avicennia marina*, *Bruguiera gymnorrhiza*, *Cocos nucifera*, *Eucalyptus globulus*, *Phoenix paludosa*, *Pongamia pinnata*, *Prosopis juliflora*, *Sonneratia apetala* and *Syzygium cumini*. In the summer the predominant nectariferous taxa were *Borassus flabellifer*, *C. nucifera*, *E. globulus*, *Syzygium cumini*, *Terminalia arjuna*, *Aegiceras corniculatum*, *P. paludosa* and *Sonneratia apetala* while those of the winter were *Brassica nigra*, *Coriandrum sativum*, *Ziziphus jujuba*, *Alstonia scholaris*, *E. globulus* and *Bruguiera gymnorrhiza*. Very low (<0.09) HDE/P for 98% of the samples and absence of toxic palynotaxa assure that these honeys are suitable for human consumption. Quite extended honey flow period with spring and summer as best forage seasons for the honeybees and occurrence of 82% of these honeys with APC Group II, III and IV justify the sustainability of the present study area for establishing moderate to large-scale apicultural entrepreneurship. This should improve the socio-economic status of the people of this region.

Introduction

Honey is produced by mutual interactions between bees and nectariferous plants. Microscopic analysis of pollen grains of natural honeys known as melissopalynology, allows identification of the different nectar sources over the season. Bees use these sources for the production of honey in a region, classifying the honey botanically and geographically according to its origin [1], [2], [3]. Melissopalynology is therefore extremely useful for hive management and allows the identification of likely periods of production of unifloral honey (honey from only one floral source), which has high commercial value [4], [5]. Usually the beekeepers do not have information of all the important nectar plants contributing to honey production and thus pollen analysis proves to be a useful guide to beekeeping in a region [6].

The per capita income of people in the coastal state of Orissa, is among those of the seven poorest states of India during 2010–2011 which amounts to $ 600 as against the Indian national figure of $1000 [7]. Moreover during 2009–2010 the rural poverty line of this state was as low as approximately $0.30 per day, against the urban poverty line $0.40 per day [8]. Tribal populations and forest dwellers in the coastal districts of Orissa viz. Kolha, Mundu, Santal, Panpano, Shabar, Gokha, Dhoba, Kondhs [9] often depend on honey collection from wild hives as their traditional profession. It provides valuable nutrition in the form of honey, protein-rich pollen and brood for their family. In addition bee products contribute important ingredients of folk and traditional medicine. Melissopalynological analysis and its application may thus improve the economic status of the local people of an area [10], [11]. Approximately 112 families, 370 genera and 632 species of angiosperms represent high floristic diversity in Orissa [12] that can be exploited by the beekeeping industry. As there are only a few small-scale beekeepers in Orissa producing honey for the local market and personal consumption and are hardly sponsored by the Government, only 10 kg of honey on an average is produced per hive-box per year [13].

Bhadrak and Kendrapara (20°20′ to 22°11′ N, 82°39′ to 87°01′ E) are two coastal districts of Orissa with dry deciduous and mangrove forests and a vast stretch of coast. These are bounded on the north by the Baleshwar district, Kendujhar, Jajpur and Cuttack districts on the west, Jagatsinghapur district on the south and Bay of Bengal in the east (Fig 1). The climate of the two coastal districts under study is tropical - moist sub humid to dry sub humid type. It belongs to the mega thermal type with very high temperature during the months of April and May. The
rainfall in this area is mostly contributed by the southwest monsoon during the months of June to September [12], [28]. The predominant plants of this area include Acacia nilotica, Acanthus ilicifolius, Aegle marmelos, Aegialitis rotundifolia, Aegiceras corniculatum, Aglaia coccinea, Amaranthus viridis, Antigonon leptopus, Avicennia officinalis, Avicennia marina, Barringtonia acutangula, Bauhinia purpurea, Borassus flabellifer, Bruguiera gymnorrhiza, Caparvis indica, Ceiba pentandra, Clerodendron inerme, Cocos nucifera, Gratama religiosa, Dalbergia tonkinensis, Diospyros ebenum, Eucalyptus globulus, Eupatorium odoratum, Euphorbia longa, Excoecaria agallocha, Fimbristylis falcata, Grewia tilaefolia, Guettarda speciosa, Hentiera fomes, H. littoralis, Hibiscus tiliaceus, Hydrophyllax maritime, Lagerstroemia parviflora, Madhuca indica, Mangifera indica, Merope angulata, Mikania scandens, Mimoso pudica, Myristachya weightiana, Ocimum sanctum,
| Honey samples, extraction source area and month of collection | pH & Color of the honey samples | Floristic nature, Bee species and the season to which honey samples belong | APC (1/10 g) & Group of honey | HDE/P and toxic pollen grains, if any | Bee-plant Species/Melissopalynotaxa (and their Families) recovered | No. of pollen grains & frequency of their occurrence (in %) |
|---|---|---|---|---|---|---|
| 1.VnTa-1 (Apiary, Banta, July) | 5.9, Yellowish brown | Multifloral, A. cerana indica, Summer | 18500, I | 14/227 = 0.06 | Syzygium cumini (Myrtaceae) | 96 (42.29) |
| | | | | | Barringtonia acutangula (Lecythidaceae) | 49 (21.59) |
| | | | | | Saraca asoca (Fabaceae) | 21 (9.25) |
| | | | | | Ocimum sanctum (Lamiaceae) | 03 (1.32) |
| | | | | | Alternanthera sessilis (Amarananthaceae) | 12 (5.29) |
| | | | | | Mimosa pudica (Fabaceae) | 17 (7.49) |
| | | | | | Borassus flabellifer (Arecaceae) | 29 (12.78) |
| | | | | | Total Number of Pollen grains counted | 227 |
| 2.VnTa-2 (Squeezed, Banta, April) | 6.2, Yellowish brown | Multifloral, A. dorsata, Spring | 95500, II | 29/662 = 0.04 | Tecoma stans (Bignoniaceae) | 114 (17.22) |
| | | | | | Sesamum indicum (Pedaliaceae) | 27 (4.08) |
| | | | | | Eucalyptus globulus (Myrtaceae) | 106 (16.01) |
| | | | | | Syzygium cumini (Myrtaceae) | 235 (35.50) |
| | | | | | Punica granatum (Punicaceae) | 19 (2.87) |
| | | | | | Borassus flabellifer (Arecaceae) | 21 (3.17) |
| | | | | | Barringtonia acutangula (Lecythidaceae) | 08 (1.21) |
| | | | | | Jasminum oleoides (Oleaceae) | 29 (4.38) |
| | | | | | Prosopis juliflora (Fabaceae) | 16 (2.42) |
| | | | | | Heliotropium indicum (Boraginaceae) | 25 (3.78) |
| | | | | | Aegle marmelos (Rutaceae) | 62 (9.37) |
| | | | | | Total Number of Pollen grains counted | 662 |
| 3.VnTa-3 (Apiary, Banta, January) | 6.3, Amber | Unifloral, A. florea, Winter | 71200, II | 36/696 = 0.05 | Tagetes patula (Asteraceae) | 36 (5.17) |
| | | | | | Mimosa pudica (Fabaceae) | 473 (67.96) |
| | | | | | Eupatorium odoratum (Asteraceae) | 102 (14.66) |
| | | | | | Crataeva religiosa (Capparidaceae) | 72 (10.34) |
| | | | | | Zizyphus jujuba (Rhamnaceae) | 13 (1.87) |
| | | | | | Total Number of Pollen grains counted | 696 |
| 4.VdMa-2 (Squeezed, Dhamra, May) | 6.1, Light Amber | Unifloral, A. cerana indica, Spring | 63900, II | 21/598 = 0.03 | Cocos nucifera (Arecaceae) | 23 (3.85) |
| | | | | | Anacardium occidentale (Anacardiaceae) | 26 (4.35) |
| | | | | | Coriandrum sativum (Apiaceae) | 77 (12.88) |
| | | | | | Avicennia marina (Acanthaceae) | 429 (71.74) |
| | | | | | Ceriops decandra (Rhizophoraceae) | 43 (7.19) |
| | | | | | Total Number of Pollen grains counted | 598 |
| 5.VbPr-2 (Squeezed, Basudebpur, March) | 6.3, Dark brown | Unifloral, A. cerana indica, Winter | 26800, II | 67/188 = 0.35 | Anacardium occidentale (Anacardiaceae) | 58 (30.85) |
| | | | | | Coriandrum sativum (Apiaceae) | 91 (48.40) |
| | | | | | Phoenix sylvestris (Arecaceae) | 39 (20.74) |
| | | | | | Total Number of Pollen grains counted | 188 |
| 6.VbPr-3 (Squeezed, Basudebpur, May) | 5.5, Light yellow | Multifloral, A. florea, Spring | 25600, II | 16/587 = 0.02 | Brassica nigra (Brassicaceae) | 191 (32.54) |
| | | | | | Sclericha oleosa (Sapindaceae) | 95 (16.18) |
| | | | | | Cocos nucifera (Arecaceae) | 11 (1.87) |
| | | | | | Mangifera indica (Anacardiaceae) | 30 (5.11) |
| | | | | | Eucalyptus globulus (Myrtaceae) | 209 (35.60) |
| Honey samples, extraction source area and month of collection | pH & Color of the honey samples | Floristic nature, Bee species and the season to which honey samples belong | APC (1/10 g) & Group of honey | HDE/P and toxic pollen grains, if any | Bee-plant Species/Melisso palynotaxa (and their Families) recovered | No. of pollen grains & frequency of their occurrence (in %) |
|-------------------------------------------------------------|--------------------------------|-------------------------------------------------|-----------------|---------------------------------|-------------------------------------------------|------------------------------------------------|
| 7.Vdrl-1 (Squeezed, Bhadrak, April)                         | 5.7, Amber                     | Multifloral, A. florea, Spring                  | 54400, II       | 48/559 = 0.08                   | Phoenix sylvestris (Areaceae)                    | 135 (24.15)                                      |
|                                                            |                                |                                                 |                |                                 | Cocos nucifera (Areaceae)                        | 7 (1.25)                                         |
|                                                            |                                |                                                 |                |                                 | Peristrope bicalculata (Acanthaceae)             | 75 (13.42)                                      |
|                                                            |                                |                                                 |                |                                 | Capparis indica (Capparidaceae)                 | 92 (16.46)                                      |
|                                                            |                                |                                                 |                |                                 | Coriandrum sativum (Apiaceae)                   | 37 (6.62)                                       |
|                                                            |                                |                                                 |                |                                 | Salmalia malabarica (Bombacaceae)               | 18 (3.22)                                       |
|                                                            |                                |                                                 |                |                                 | Mimosa pudica (Fabaceae)                        | 174 (31.13)                                     |
|                                                            |                                |                                                 |                |                                 | Poaceae                                         | 8 (1.43)                                        |
|                                                            |                                |                                                 |                |                                 | Carum copticum (Apiaceae)                       | 13 (2.33)                                       |
|                                                            |                                |                                                 |                |                                 | Total Number of Pollen grains counted           | 559                                             |
| 8.Vcbl-1 (Squeezed Chandbali, July)                         | 6.1, Brown                     | Unifloral, A. cerana indica, Summer             | 50800, II       | 41/683 = 0.06                   | Zizyphus jujuba (Rhamnaceae)                     | 44 (8.59)                                       |
|                                                            |                                |                                                 |                |                                 | Total Number of Pollen grains counted           | 512                                             |
| 9.Vdi-1 (Apiary, Tihidi, February)                          | 6.0, Reddish brown             | Unifloral, A. cerana indica, Winter             | 380000, III     | 7/512 = 0.01                    | Mimosa pudica (Fabaceae)                        | 468 (91.41)                                     |
|                                                            |                                |                                                 |                |                                 | Total Number of Pollen grains counted           | 672                                             |
| 10.Vtdi-2 (Squeezed, Tihidi, April)                         | 5.7, Yellow                    | Multifloral, A. dorsata, Spring                 | 23000, II       | 8/519 = 0.01                   | Zizyphus jujuba (Rhamnaceae)                     | 51 (9.83)                                       |
|                                                            |                                |                                                 |                |                                 | Total Number of Pollen grains counted           | 519                                             |
| 11.Vbnd-1 (Apiary, Balimunda, May)                          | 6.2, Brown                     | Multifloral, A. cerana indica, Spring           | 7400, I         | 6/69 = 0.08                    | Brassica nigra (Brassicaceae)                   | 8 (11.59)                                       |
|                                                            |                                |                                                 |                |                                 | Total Number of Pollen grains counted           | 519                                             |

Table 1. Cont.
**Table 1.** Cont.

| Honey samples, extraction source area and month of collection | pH & Color of the honey samples | Floristic nature, Bee species and the season to which honey samples belong | APC (1/10 g) & Group of honey | HDE/P and toxic pollen grains, if any | Bee-plant Species/Melissopolyanotaxa (and their Families) recovered | No. of pollen grains & frequency of their occurrence (in %) |
|---------------------------------------------------------------|---------------------------------|--------------------------------------------------------------------------|-------------------------------|------------------------------------------|---------------------------------------------------------------|-------------------------------------------------------------|
| 12.Vind-2 (Squeezed, Ballimunda, February)                    | 5.9, Amber                       | Unifloral, A. cerana indica, Winter                                      | 8100, 1                       | 2/61 = 0.03                              | *Mimosa pudica* (Fabaceae)                                      | 11 (18.03)                                                  |
|                                                               |                                 |                                                                          |                               |                                          | *Madhuca indica* (Sapotaceae)                                   | 16 (26.23)                                                  |
|                                                               |                                 |                                                                          |                               |                                          | *Tecoma stans* (Bignoniaceae)                                   | 3 (4.92)                                                    |
|                                                               |                                 |                                                                          |                               |                                          | *Zizyphus jujuba* (Rhamnaceae)                                  | 31 (50.82)                                                  |
|                                                               |                                 |                                                                          |                               |                                          | Total Number of Pollen grains counted                           | 69                                                          |
| 13.Vdnr-1 (Squeezed, Dhamnagar, May)                          | 5.5, Light yellow amber          | Unifloral, A. dorsata, Spring                                           | 75900, II                     | 14/579 = 0.02                              | *Syzygium cumini* (Myrtaceae)                                   | 487 (84.11)                                                  |
|                                                               |                                 |                                                                          |                               |                                          | *Cocos nucifera* (Areaceae)                                     | 9 (1.55)                                                    |
|                                                               |                                 |                                                                          |                               |                                          | *Coriandrum sativum* (Apiaceae)                                 | 13 (2.25)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | *Jasminum oleoides* (Oleaceae)                                  | 15 (2.59)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | *Callistemon citrinus* (Myrtaceae)                              | 41 (7.08)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | *Tridax procumbens* (Asteraceae)                                | 14 (2.42)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | Total Number of Pollen grains counted                           | 579                                                         |
| 14.Vdnr-2 (Apiary, Dhamnagar, July)                           | 5.9, Yellowish amber             | Unifloral, A. cerana indica, Summer                                      | 16200, I                      | 12/440 = 0.02                              | *Syzygium cumini* (Myrtaceae)                                   | 412 (93.64)                                                  |
|                                                               |                                 |                                                                          |                               |                                          | *Bauhinia purpurea* (Fabaceae)                                  | 14 (3.18)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | *Barringtonia acutangula* (Lecythidaceae)                       | 14 (3.18)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | Total Number of Pollen grains counted                           | 440                                                         |
| 15.Vdnr-3 (Squeezed, Dhamnagar, June)                         | 5.5, Yellowish brown             | Multifloral, A. dorsata, Winter                                         | 56800, II                     | 14/648 = 0.02                              | *Eucalyptus gobulus* (Myrtaceae)                                | 104 (16.05)                                                  |
|                                                               |                                 |                                                                          |                               |                                          | *Cocos nucifera* (Areaceae)                                     | 34 (5.25)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | *Borassus flabellifer* (Areaceae)                               | 34 (5.25)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | *Coriandrum sativum* (Apiaceae)                                 | 128 (19.75)                                                 |
|                                                               |                                 |                                                                          |                               |                                          | *Rosa chinensis* (Rosaceae)                                     | 6 (0.93)                                                    |
|                                                               |                                 |                                                                          |                               |                                          | *Salmalia malabarica* (Bombacaceae)                             | 49 (7.56)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | *Carum cpticum* (Apiaceae)                                      | 55 (8.49)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | *Lagerstroemia parviflora* (Lythraceae)                         | 142 (21.91)                                                 |
|                                                               |                                 |                                                                          |                               |                                          | *Spondias dulcis* (Anacardiaceae)                               | 20 (3.09)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | *Sterculia foetida* (Sterculiaceae)                             | 76 (11.73)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | Total Number of Pollen grains counted                           | 648                                                         |
| 16.Vard-1 (Apiary, Aradi, 5.3, Light brown May)               | Unifloral, A. cerana indica, Spring | 35500, II                           | 18/586 = 0.03                         |                                           | *Syzygium cumini* (Myrtaceae)                                   | 579 (98.81)                                                  |
|                                                               |                                 |                                                                          |                               |                                          | *Coriandrum sativum* (Apiaceae)                                 | 7 (1.19)                                                    |
|                                                               |                                 |                                                                          |                               |                                          | Total Number of Pollen grains counted                           | 586                                                         |
| 17.Vdrk-2 (Squeezed, Bhadrak, December)                       | 5.6, Yellow                      | Unifloral, A. dorsata, Winter                                           | 81000, II                     | 10/674 = 0.01                              | *Cleome viscosa* (Cappadaceae)                                  | 167 (24.77)                                                  |
|                                                               |                                 |                                                                          |                               |                                          | *Grewia tilaefolia* (Tiliaceae)                                 | 35 (5.19)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | *Anacardium occidentale* (Anacardiaceae)                        | 15 (2.22)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | *Carum cpticum* (Apiaceae)                                      | 10 (1.48)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | *Salmalia malabarica* (Malvaceae)                               | 04 (0.59)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | *Alstonia scholaris* (Apocynaceae)                              | 396 (58.75)                                                  |
|                                                               |                                 |                                                                          |                               |                                          | *Schleichera oleosa* (Sapindaceae)                              | 47 (6.97)                                                   |
|                                                               |                                 |                                                                          |                               |                                          | Total Number of Pollen grains counted                           | 674                                                         |
| Honey samples, extraction source area and month of collection | pH & Color of the honey samples | Floristic nature, Bee species and the season to which honey samples belong | APC (/10 g) & Group of honey | HDE/P and toxic pollen grains, if any | Bee-plant Species/Melissa polynotaxa (and their Families) recovered | No. of pollen grains & frequency of their occurrence (in %) |
|-------------------------------------------------------------|--------------------------------|-------------------------------------------------------------------------------------------------|-----------------------------|---------------------------------|----------------------------------------------------------------|---------------------------------------------------------------|
| 18.Vcbl-2 (Squeezed, Chandbali, April)                       | 4.9, Amber                     | Unifloral, A. cerana indica, Summer                                                             | 166000, III                | 5/608 = 0.01                   | Anacardium occidentale (Anacardiaceae)                           | 32 (5.36)                                                     |
|                                                              |                                |                                                                                                 |                             |                                 | Aegiceras corniculatum (Myrsinaceae)                             | 457 (76.67)                                                  |
|                                                              |                                |                                                                                                 |                             |                                 | Sonneratia apetala (Lythraceae)                                  | 59 (9.89)                                                    |
|                                                              |                                |                                                                                                 |                             |                                 | Ceiba protandra (Bombacaceae)                                   | 27 (4.53)                                                    |
|                                                              |                                |                                                                                                 |                             |                                 | Pongamia pinnata (Fabaceae)                                     | 21 (3.52)                                                    |
|                                                              |                                |                                                                                                 |                             |                                 | Total Number of Pollen grains counted                          | 596                                                          |
| 19.Vdma-1 (Squeezed, Dhamra, February)                       | 5.2, Light brown               | Unifloral, A. cerana indica, Winter                                                             | 526500, V                  | 4/665 = 0.01                   | Eucalyptus globulus (Myrtaceae)                                 | 05 (0.75)                                                    |
|                                                              |                                |                                                                                                 |                             |                                 | Cocos nucifera (Areaceae)                                       | 03 (0.45)                                                    |
|                                                              |                                |                                                                                                 |                             |                                 | Bruguiera gymnorrhiza (Rhizophoraceae)                          | 649 (97.59)                                                  |
|                                                              |                                |                                                                                                 |                             |                                 | Sonneratia apetala (Lythraceae)                                 | 8 (1.20)                                                     |
|                                                              |                                |                                                                                                 |                             |                                 | Total Number of Pollen grains counted                          | 665                                                          |
| 20.Vbpr-1 (Apiary, Basudebpur, July)                        | 5.7, Brown                     | Unifloral, A. cerana indica, Spring                                                             | 64900, II                  | 48/530 = 0.09                  | Borassus flabelifer (Arecaceae)                                 | 6 (1.13)                                                     |
|                                                              |                                |                                                                                                 |                             |                                 | Pongamia pinnata (Fabaceae)                                     | 429 (80.94)                                                  |
|                                                              |                                |                                                                                                 |                             |                                 | Coriandrum sativum (Apiaceae)                                   | 21 (3.96)                                                    |
|                                                              |                                |                                                                                                 |                             |                                 | Phoenix sylvestris (Areaceae)                                   | 7 (1.32)                                                     |
|                                                              |                                |                                                                                                 |                             |                                 | Anacardium occidentale (Anacardiaceae)                          | 24 (4.52)                                                    |
|                                                              |                                |                                                                                                 |                             |                                 | Mikania scandens (Asteraceae)                                   | 13 (2.45)                                                    |
|                                                              |                                |                                                                                                 |                             |                                 | Phlogacanthus thysiflorus (Acanthaceae)                         | 15 (2.83)                                                    |
|                                                              |                                |                                                                                                 |                             |                                 | Total Number of Pollen grains counted                          | 530                                                          |
| 21.Vdma-3 (Squeezed, Dhamra, July)                          | 5.6, Light brown               | Unifloral, A. cerana indica, Spring                                                             | 93000, II                  | 0/573 = 0.00                   | Fabaceae                                                       | 36 (6.28)                                                    |
|                                                              |                                |                                                                                                 |                             |                                 | Acanthus ilicifolius (Acanthaceae)                              | 537 (93.71)                                                  |
|                                                              |                                |                                                                                                 |                             |                                 | Total Number of Pollen grains counted                          | 573                                                          |
| 22.Khsi–1 (Squeezed, Hatsahi, June)                        | 5.5, Light amber               | Unifloral, A. florea, Spring                                                                   | 150100, III                | 5/658 = 0.01                  | Eucalyptus globulus (Myrtaceae)                                 | 486 (85.56)                                                  |
|                                                              |                                |                                                                                                 |                             |                                 | Antigonon leptopus (Polygonaceae)                               | 36 (6.33)                                                    |
|                                                              |                                |                                                                                                 |                             |                                 | Amaranthus viridis (Amaranthaceae)                              | 46 (8.09)                                                    |
|                                                              |                                |                                                                                                 |                             |                                 | Total Number of Pollen grains counted                          | 568                                                          |
| 23.Krka-1 (Apiary, Rajkanika, July)                        | 4.8, Yellowish brown           | Unifloral, A. cerana indica, Spring                                                             | 98000, II                  | 7/536 = 0.01                  | Syzygium cuminii (Myrtaceae)                                    | 289 (53.91)                                                  |
|                                                              |                                |                                                                                                 |                             |                                 | Grewia tiliaefera (Tiliaceae)                                   | 231 (43.09)                                                  |
|                                                              |                                |                                                                                                 |                             |                                 | Ocimum sanctum (Lamiaceae)                                      | 16 (2.98)                                                    |
|                                                              |                                |                                                                                                 |                             |                                 | Total Number of Pollen grains counted                          | 536                                                          |
| 24.Krka-2 (Squeezed, Rajkanika, May)                        | 5.0, Yellowish amber           | Unifloral, A. dorsata, Spring                                                                  | 89500, II                  | 4/482 = 0.01                  | Syzygium cuminii (Myrtaceae)                                    | 367 (76.14)                                                  |
|                                                              |                                |                                                                                                 |                             |                                 | Ocimum sanctum (Lamiaceae)                                      | 83 (17.21)                                                    |
|                                                              |                                |                                                                                                 |                             |                                 | Barringtonia acutangula (Lecythidaceae)                         | 32 (6.63)                                                    |
|                                                              |                                |                                                                                                 |                             |                                 | Total Number of Pollen grains counted                          | 482                                                          |
| 25.Krka-3 (Squeezed, Rajkanika, July)                        | 5.5, Brown                     | Unifloral, A. cerana indica, Summer                                                             | 95000, II                  | 4/545 = 0.01                  | Sonneratia apetala (Lythraceae)                                 | 138 (25.32)                                                  |
|                                                              |                                |                                                                                                 |                             |                                 | Aegiceras corniculatum (Myrsinaceae)                            | 366 (67.15)                                                  |
### Table 1. Cont.

| Honey samples, extraction source area and month of collection | pH & Color of the honey samples | Floristic nature, Bee species and the season to which honey samples belong | APC (/10 g) & Group of honey | HDE/P and toxic pollen grains, if any | Bee-plant Species/Melissa palynotaxa (and their Families) recovered | No. of pollen grains & frequency of their occurrence (in %) |
|-------------------------------------------------------------|--------------------------------|--------------------------------------------------------------------------|-----------------------------|----------------------------------|-------------------------------------------------------------------|----------------------------------------------------------|
| 26.Kaul-1 (Apiary, Aul, July)                               | 5.4, Light brown              | Unifloral, A. cerana indica, Summer                                       | 17600, I                    | 9/158 = 0.05                    | Eucalyptus globulus (Myrtaceae)                                   | 35 (22.15)                                               |
|                                                            |                               |                                                                          |                             |                                  | Total Number of Pollen grains counted                              |                                                          |
| 27.Kaul-2 (Squeezed, Aul, March)                            | 4.7, Light yellow             | Unifloral, A. florea, Winter                                             | 60400, II                   | 39/379 = 0.10                   | Brussica nigra (Brassicaceae)                                     | 243 (64.11)                                               |
|                                                            |                               |                                                                          |                             |                                  | Total Number of Pollen grains counted                              |                                                          |
| 28.Kaul-3 (Apiary, Aul, July)                               | 5.5, Amber                     | Unifloral, A. cerana indica, Spring                                       | 196000, III                 | 14/576 = 0.02                   | Mimosa pudica (Fabaceae)                                          | 465 (80.72)                                               |
|                                                            |                               |                                                                          |                             |                                  | Total Number of Pollen grains counted                              |                                                          |
| 29.Kmrm-1 (Squeezed, Rajnagar, February)                    | 5.3, Light brown              | Multifloral, A. dorsata, Spring                                         | 210000, III                 | 6/545 = 0.01                   | Aegialitis rotundifolia (Plumbaginaceae)                         | 19 (3.48)                                                 |
|                                                            |                               |                                                                          |                             |                                  | Bruguiera gymnorrhiza (Rhizophoraceae)                            | 203 (37.24)                                               |
|                                                            |                               |                                                                          |                             |                                  | Phoenix paludosa (Arecaceae)                                     | 238 (43.66)                                               |
|                                                            |                               |                                                                          |                             |                                  | Casuarina equisetifolia (Casuarinaceae)                           | 85 (15.59)                                                |
|                                                            |                               |                                                                          |                             |                                  | Total Number of Pollen grains counted                              | 545                                                       |
| 30.Kmrm-2 (Squeezed, Rajnagar, April)                       | 4.6, Yellowish brown          | Unifloral, A. dorsata, Spring                                            | 240000, III                 | 11/595 = 0.01                  | Bruguiera gymnorrhiza (Rhizophoraceae)                            | 522 (87.73)                                               |
|                                                            |                               |                                                                          |                             |                                  | Solarum melongena (Solanaceae)                                   | 56 (9.41)                                                 |
|                                                            |                               |                                                                          |                             |                                  | Unidentified                                                      | 17 (2.85)                                                 |
|                                                            |                               |                                                                          |                             |                                  | Total Number of Pollen grains counted                              | 595                                                       |
| 31.Kmrm-3 (Squeezed, Rajnagar, June)                        | 5.4, Yellowish amber          | Unifloral, A. cerana indica, Summer                                       | 109000, III                 | 9/472 = 0.01                   | Syzygium cumini (Myrtaceae)                                       | 90 (19.06)                                                |
|                                                            |                               |                                                                          |                             |                                  | Bruguiera gymnorrhiza (Rhizophoraceae)                            | 199 (50.37)                                               |
|                                                            |                               |                                                                          |                             |                                  | Phoenix paludosa (Arecaceae)                                     | 240 (50.84)                                               |
|                                                            |                               |                                                                          |                             |                                  | Total Number of Pollen grains counted                              | 472                                                       |
| 32.Kbka-1 (Squeezed, Bhitkanika, July)                     | 5.1, Amber                     | Unifloral, A. cerana indica, Summer                                       | 515000, IV                  | 0/565 = 0.00                   | Aegiceras corniculatum (Myrsinaceae)                             | 516 (91.32)                                               |
|                                                            |                               |                                                                          |                             |                                  | Total Number of Pollen grains counted                              | 472                                                       |
| 33.Kbka-2 (Squeezed, Bhitkanika, February)                  | 5.5, Yellowish brown          | Unifloral, A. cerana indica, Winter                                       | 296000, III                 | 18/395 = 0.04                  | Bruguiera gymnorrhiza (Rhizophoraceae)                            | 199 (50.37)                                               |
|                                                            |                               |                                                                          |                             |                                  | Phoenix paludosa (Arecaceae)                                     | 240 (50.84)                                               |
|                                                            |                               |                                                                          |                             |                                  | Total Number of Pollen grains counted                              | 472                                                       |
| 34.Kbka-3 (Squeezed, Bhitkanika, June)                     | 4.9, Amber                     | Multifloral A. cerana indica Spring                                     | 965000, II                  | 0/461 = 0.00                   | Bruguiera gymnorrhiza (Rhizophoraceae)                            | 193 (41.86)                                               |
|                                                            |                               |                                                                          |                             |                                  | Total Number of Pollen grains counted                              | 395                                                       |
| Honey samples, extraction source area and month of collection | pH & Color of the honey samples | Floristic nature, Bee species and the season to which honey samples belong | APC (/10 g) & Group of honey | HDE/P and toxic pollen grains, if any | Bee-plant Species/Melisso polyotaxa (and their Families) recovered | No. of pollen grains & frequency of their occurrence (in %) |
|-------------------------------------------------------------|-------------------------------|-----------------------------------------------------------------|-----------------|-----------------------------------|-----------------------------------------------------------------|--------------------------------------------------|
| 35.Ksba-1 (Squeezed, Satabhaya, April)                       | 5.6, Yellowish brown          | Unifloral, A. dorsata, Spring                                    | 195000, III     | 3/573 = 0.005                    | Bruguiera gymnorrhiza (Rhzophoraceae)                             | Derris scandens (Fabaceae) 100 (21.69)             |
|                                                            |                               |                                                                 |                 |                                   | Total Number of Pollen grains counted                             | Aegialitis rotundifolia (Plumbaginaceae) 168 (36.44) |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Total Number of Pollen grains counted 461            |
| 36.Ksba-2 (Squeezed, Satabhaya, February)                    | 4.7, Light brown              | Unifloral, A. cerana indica, Spring                             | 190000, III     | 0/551 = 0.00                     | Bruguiera gymnorrhiza (Rhzophoraceae)                             | Phoenix paludosa (Areccaceae) 302 (54.80)          |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Amaranthus viridis (Amaranthaceae) 47(8.52)           |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Total Number of Pollen grains counted 551            |
| 37.Ksba-3 (Squeezed, Satabhaya, June)                        | 5.6, Light amber              | Unifloral, A. cerana indica, Summer                             | 78000, II       | 2/402 = 0.004                   | Aegiceras corniculatum (Myrsinaceae)                           | Amaranthus viridis (Amaranthaceae) 27 (6.71)       |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Total Number of Pollen grains counted 551            |
| 38.Kpdi-1 (Squeezed, Patamundai, June)                       | 4.8, Yellowish brown          | Unifloral, A. dorsata, Summer                                    | 13000, I        | 05/433 = 0.02                   | Eucalyptus globulus (Myrtaceae)                                 | Cocos nucifera (Areccaceae) 34 (7.85)              |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Borassus flabellifer (Areccaceae) 316 (72.97)         |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Total Number of Pollen grains counted 433            |
| 39.Kpdi-2 (Squeezed, Patamundai, April)                      | 6.4, Light yellow             | Multifloral, A. flore, Spring                                   | 17500, I        | 09/352 = 0.02                   | Eucalyptus globulus (Myrtaceae)                                 | Coriandrum sativum (Apiaceae) 102 (28.97)          |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Madhuca indica (Sapotaceae) 46 (13.06)                 |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Rosa chinensis (Rosaceae) 38 (10.79)                  |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Phoenix sylvestris (Arecaceae) 31 (8.80)              |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Moringa oleifera (Moringaceae) 43 (12.21)            |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Butea monosperma (Fabaceae) 66 (18.75)                |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Total Number of Pollen grains counted 352            |
| 40.Kpdi-3 (Squeezed, Patamundai, March)                      | 5.7, Yellowish brown          | Unifloral, A. flore, Spring                                     | 74000, II       | 03/531 = 0.01                   | Eucalyptus globulus (Myrtaceae)                                 | Mimosa pudica (Fabaceae) 79 (14.87)                |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Borassus flabellifer (Areccaceae) 33 (6.21)           |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Antigonon leptopus (Polygonaceae) 87 (16.38)          |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Amaranthus viridis (Amaranthaceae) 40 (7.53)         |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Phoenix sylvestris (Arecaceae) 24 (4.51)              |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Total Number of Pollen grains counted 531            |
| 41.Knht-1 (Apiary, Nuahat, June)                             | 6.1, Light brown              | Multifloral, A. cerana indica, Summer                           | 81500, II       | 6/567 = 0.01                    | Pongamia pinnata (Fabaceae)                                     | Grewia tiliae folia (Tiliaceae) 108 (19.04)        |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Amaranthus viridis (Amaranthaceae) 28 (4.93)          |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Madhuca indica (Sapotaceae) 55 (9.70)                 |
|                                                            |                               |                                                                 |                 |                                   |                                                                   | Borassus flabellifer (Areccaceae) 36 (6.34)           |
| Honey samples, extraction source area and month of collection | pH & Color of the honey samples | Floristic nature, Bee species and the season to which honey samples belong | APC (/10 g) & Group of honey | HDE/P and toxic pollen grains, if any | Bee-plant Species/Melissopalynotaxa (and their Families) recovered | No. of pollen grains & frequency of their occurrence (in %) |
|-------------------------------------------------------------|--------------------------------|-------------------------------------------------|-----------------------------|----------------------------------|-------------------------------------------------|-------------------------------------------------|
| 42.Knh-2 (Apiary, Nuahat, March)                            | 6.0, Light yellow Unifloral, A. cerana indica, Winter | 96000, II | 2/511 = 0.003 | Eucalyptus globulus (Myrtaceae) | 357 (72.26) |
| 43.Knh-3 (Apiary, Nuahat, May)                             | 5.6, Amber Multifloral, A. cerana indica, Summer | 155000, III | 1/526 = 0.002 | Eucalyptus globulus (Myrtaceae) | 219 (41.63) |
| 44.Kna-1 (Squeezed, Kendrapara, February)                  | 4.7, Light yellow Multifloral, A. florea, Winter | 14500, I | 17/382 = 0.04 | Mimosa pudica (Fabaceae) | 102 (26.70) |
| 45.Kna-2 (Squeezed, Kendrapara, April)                     | 5.5, Amber Unifloral, A. cerana indica, Spring | 533000, IV | 0/547 = 0.00 | Phoenix paludosa (Arecaceae) | 452 (82.63) |
| 46.Kna-3 (Apiary, Kendrapara, July)                        | 4.9, Light amber Unifloral, A. cerana indica, Summer | 503000, IV | 3/526 = 0.01 | Terminalia arjuna (Combretaceae) | 319 (60.64) |
| 47.Kmna-1 (Apiary, Mahakalpara, June)                      | 5.4, Amber Unifloral, A. cerana indica, Summer | 45000, II | 4/515 = 0.01 | Eucalyptus globulus (Myrtaceae) | 423 (82.13) |
| 48.Kmna-2 (Squeezed, Mahakalpara, May)                     | 5.2, Light brown Unifloral, A. florea, Spring | 105000, II | 7/424 = 0.01 | Borassus flabellifer (Arecaceae) | 92 (21.69) |

**Table 1. Cont.**
Orissa has been undertaken. pollen analysis of natural honey samples from these two districts of [14],[15]. In order to rectify this insufficiency of melissopalynological database the present study of qualitative and quantitative pollen analysis of natural honey samples from these two districts of Orissa has been undertaken.

**Materials and Methods**

**Ethics statement**

No specific permits were required for the described field studies. The sampling sites are not protected in any way and the field studies did not involve endangered or protected species.

**Materials**

Fifty-one natural honey samples (out of which thirty five were squeezed and sixteen were from apiary) were collected from twenty-one different areas of Bhadrak and Kendrapara districts during different seasons in 2010–2011 (Fig. 1). The honey samples were obtained directly from the honey-bearing portion of the combs of *A. cerana indica* (31 honey samples), *A. dorsata* (12 samples) and *A. florea* (8 samples) as far as possible. The honey samples were mostly analyzed immediately after collection. The pH of each sample was determined by a simple color grading method [16]. The color of the honey samples was determined by a simple color grading method [16].

**Methods**

For qualitative melissopalynological analysis, honey samples were processed by acetolysis method adopted by Erdtman [17] with some modifications recommended by the International Commission for Bee Botany [1],[2]. Ten grams of each honey sample were transferred to a pointed glass centrifuge tube (50 ml capacity), stirred with a 1 ml pipette and dissolved in 20 ml of distilled water (20–40 °C) and centrifuged for 10 min at 2000 g. The supernatant was decanted off. The process was repeated twice. The supernatant liquid was decanted off and all but the last drop is removed by placing the tube upside down at a 45° angle to allow the remaining excess liquid to be taken up on absorbent paper. The sediment obtained was treated with acetolysis mixture (acetic anhydride: conc. sulphuric acid = 9:1 v/v). The centrifuge tube containing the sediment-glycerin jelly mixture. To analyze the pollen content three pollen slides were prepared in this way from each honey sample studied and photographed under a compound microscope (Zeiss, Axioskop 2). Dried acetolysed pollen sediments were also photographed using a Scanning Electron Microscope (Carl Zeiss, Evo 40). The pollen grains were identified with the help of reference slides prepared from a collection of the local flora (Repository of spore-pollen slides of modern taxa, CUH, Palaeobotany and Palynology section, Center of Advanced Studies, Department of Botany, and University of Calcutta) and published literature [18],[19],[20],[14],[15],[21],[22].

The majority of the pollen types could be identified at the species level.
and those types that could not be identified were mentioned as unidentified.

For quantification of pollen grain types 500 pollen grains were randomly counted from each sample. Percentage frequency of the pollen taxa in all the samples was calculated. Unacetolysed honey samples were examined for computing the (HDE/P) ratio of Honey Dew Elements (HDE) and total number of pollen grains (P) of bee-plant taxa in each sample. Recommendations of the International Commission for Bee Botany [1] were followed for determination of the frequency classes. Pollen frequency classes are determined as predominant pollen (represented by $\geq 15\%$ of the pollen grains counted), secondary pollen (16–45%), important minor pollen (3–15%) and minor pollen (less than 3%). A honey sample with one predominant pollen type was regarded as unifloral (and multifloral otherwise).

The absolute pollen count (APC) of the honey samples (i.e. the number of pollen grains per 10 g of honey) was calculated using a haemocytometer [23]. The samples were categorized under various groups in conformity with the universally followed grading parameters [1] viz., Group I (<20,000 pollen grains), Group II (20,000–100,000), Group III (100,000–500,000), Group IV (500,000–1,000,000) and Group V (>1,000,000).

A nectar calendar of the study area was constructed from the palynotaxa frequency data by considering all predominant pollen types in the unifloral honeys as chief nectar sources and all pollen types represented by at least 10% in the honey samples as alternative nectar sources. The seasons when a large amount of nectar from flowers is available are Honey Flow Period while the seasons when nectar source is limited and/or not available to the honey bees (for example due to heavy rain during the rainy season bee forage is affected seriously) are Honey Dearth Period.

We have attempted a multivariate analysis through Principal Component Analysis (PCA) of the melissopalynological data to evaluate the classification of these natural honey samples according to their botanical origin. Quality control methods, in conjunction with multivariate statistical analysis, have proved to be potent for classifying honey from different geographic regions [24], [25]. The matrix comprised the absolute values of all the parameters measured for the taxa recorded in each sample. PAST 2.17 version 3.0.9 [26] is used for principal component analysis (PCA) from the pollen data that are explored to derive the first principal components which are further analyzed by Microcal Origin version 6.0 [27] to examine the grouping of the samples in order to understand the relative distribution of unifloral honey samples according to their botanical origin.

**Results**

Melissopalynological study assesses the status of native flora [4]. On the basis of microscopic analysis of fifty-one honey samples eighty-two angiospermic taxa belonging to forty-four families are demonstrated as bee plants in these coastal districts of India (Table 1). Three species of honeybees viz., *Apis cerana indica*, *A. dorsata* and *A. florea* contribute to these honeys. Thirty-seven samples are proved to be unifloral, twenty-five of which are contributed by *Apis cerana indica*, seven by *A. dorsata* and the remaining five by *A. florea*. Fourteen samples are multifloral, five of which contributed by *A. cerana indica*, five by *A. dorsata* and the remaining four by *A. florea*. The extent to which a given honey is derived from different plant sources can be deduced from the frequencies of the different pollen in it [28]. The predominant nectariferous taxa are *Acanthus ilicifolius*, *Aegiceras corniculatum*, *Alstonia scholaris*, *Avicennia marina*, *Borassus flabellifer*, *Brassica nigra*, *Bruguiera gymnorrhiza*, *Cocos nucifera*, *Coriandrum sativum*, *Eucalyptus globulus*, *Phoenix paludosa*, *Pongamia pinnata*, *Prosopis juliflora*, *Sonneratia apetala*, *Syzygium cumini*, *Terminalia arjuna*, and *Zizyphus jujuba*. Thirty

![Figure 2. Frequency (%) of palynotaxa recovered.](https://doi.org/10.1371/journal.pone.0094572.g002)
Figure 3. A) Photomicrographs and scanning electron micrographs of some of the significant and characteristic pollen assemblage recovered from the natural honey samples of coastal district of Bhadrak and Kendraparha, India. a. Schleicheria oleosa (S.o) and Cleome viscosa (C.v) found in sample Vdhr-2; b. Casuarina equisetifolia (C.e) and Bruguiera gymnorrhiza (B.g) found in sample Ksna-1; c. Sonneratia apetala (S.a), Aegiceras corniculatum (A.c) and Amaranthus viridis (A.v) found in sample Ksba-3; d. Brassica nigra (B.n) and Schleicheria oleosa (S.o) in sample Vbpr-3; e. Syzygium cumini (S.c) and Barringtonia acutangula (B.a) in sample Krka-3; f. Aegiceras corniculatum (A.c) and Sonneratia apetala (S.a) in sample Vbhr-2; g. Acanthus ilicifolius (A.i) in sample Vdna-3; h. Mimosa pudica (M.p) and Zizyphus jujuba (Z.j) in sample Vtdi-1; i. Terminalia arjuna (T.a) and Lagerstroemia parviflora (L.p) in sample Kna-3; B. a. Aegiceras corniculatum (A.c), Celia protandra (C.p) and Sonneratia apetala (S.a) in sample Krka-3; b. Aegiceras corniculatum (A.c) in sample Kbka-1; c. Bruguiera gymnorrhiza (B.g) and Aegialitis rotundifolia (A.r) in sample Kbka-3; d. Pongamia pinnata (P.p) and Grewia tilaefolia (G.t) in sample Knt-1; e. Bruguiera gymnorrhiza (B.g) and Amaranthus viridis (A.v) in sample Ksba-2; f. Cocos nucifera (C.n) and Madhuca indica (M.i) in sample Kkb-2; g. Phoenix sylvestris (P.s) and Mimosa pudica (M.p) in sample Vdrk-1; h. Tecoma stans (T.s) and Syzygium cumini (S.c) in sample Vnta-2; i. Prosopis juliflora (P.j) and Borassus flabellifer (B.f) in sample Kmpa-2. Italicized initials within parenthesis after each palynotaxon above is given (as suggested by the referee) to indicate species level identification of the taxon in the respective figures of Fig.3.A and B. Bar = 10 μm unless otherwise mentioned (original magnification: 400× and 1000×; d and g of Plate 1 and g of Plate 2 are scanning electron micrographs).

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two secondary pollen taxa are recorded among which the significant are Anacardium occidentale, Antigonon leptopus, Barringtonia acutangula, Borassus flabellifer, Cleome viscosa, Derris scandens, Eupatorium odoratum, Grevia tilaefolia, Lagerstroemia parviflora, Madhuca indica, Phoenix sylvestris and Psidium guajava (Table 1). Mimosa pudica, Anamnitis rhizophora and Poaceae types do not have nectar, so probably the bees forage these plants as a pollen source or are common probably because they become attached to the honeybees due to the close proximity of the non-nectariferous taxa to nectariferous ones. The absolute Pollen Count (APC) per 10 g of honey samples indicates that most of the samples (approximately 55%) belong to Group II (27 samples) and III (11 samples) 9 samples to Group I while 4 samples belong to Group IV. Absolute count and percentage frequency in all the samples are graphically represented in Fig. 2. HDE/P of the samples ranges from 0.0 to 0.1 with the lowest value (0.0) shown by the samples Vdna-III, Kura-II, Ksba-II, Kba-I and Kkba-III and highest value (0.1) by Kaul-II (Table 1). The pH of the samples ranges from 4.6 to 6.4 with lowest pH (4.6) shown by the sample Krrn-II and highest pH (6.4) by Kpdi-II. The color range of the samples varies from light yellow (in eight samples) to dark brown (in the sample Vbhr-II). Photomicrographs and scanning electron micrographs of the significant and predominant palynotaxa recovered from the honey samples are recorded and presented in Fig. 3.A and B. Three taxa could not be identified (and are referred to as unidentified). There are remarkable differences in the overall pollen contents of the honeys of Bhadrak and Kendraparha despite their geographical proximity. Fifty nine percent of the total honey samples are from Kendraparha while 41% of the samples are from Bhadrak. Aegiceras corniculatum, Bruguiera gymnorrhiza, Mimosa pudica and Syzygium cumini represent the predominant palynotaxa in both districts but Anacardium occidentale, Alstonia scholaris, Asenavia marina, Corisandrum sativum, Pongamia pinnata and Zizyphus jujuba are found to be predominant palynotaxa in Bhadrak. Whereas Borassus flabellifer, Brassica nigra, Cocos nucifera, Eucalyptus globulus, Phoenix paludosa, Prosopis juliflora, Sonneratia apetala and Terminalia arjuna are found to be predominant in Kendraparha. All three honeybees A. cerana indica, A. dorsata and A. florea prefer arboreal families especially Arecaceae, Myrtaceae and Fabaceae and in the mangrove areas Rhizophoraceae, Myrsinaceae and Lyrhaceae. A. dorsata never
forage on Alternanthera sessilis, Brassica nigra, Cleome gynandra, Cleome viscosa, Mikania scandens probably due to their feeble and slender peduncles and the small size of these flowers. A. florea often forages on herbs near the agricultural fields. HDE/P values (Mean±SD) are lower (0.01±0.02) in Kendrapara samples than those in Bhadrak (0.49±0.07).

The nectar calendar of the study area shows that the overall honey flow period is from November to June which is divided into a Spring Honey Flow Period (Spring HFP) during February-April, a Summer Honey Flow Period (Summer HFP) from May to June and a Winter Honey Flow Period (Winter HFP) during November-January (Fig. 4). July to October is recognized as the Honey Dearth Period (HDP) because few plants serve as nectar sources possibly due to the heavy monsoon in the area. The score plot of the two principal components (PC1 and PC2) for the classification of honey samples according to their botanical origin is determined (Fig. 5). A distinct separation of honey samples is observed according to their botanical origin. The samples that are grouped in the clusters have pollen grains in common and the samples in this work are clustered into five groups. The left uppermost ellipse is a cluster in which the honey samples with Syzygium as predominant pollen type are grouped together. The right uppermost cluster includes the samples with Aegiceras as the predominant pollen type, the middle horizontal cluster represents the honey samples with Aegiceras as the secondary pollen type and the lowermost cluster includes honey samples with Bruguiera as the predominant pollen type while the middle vertical cluster includes all the remaining honey samples without Syzygium, Aegiceras and Bruguiera pollen grains. Principal Component Analysis has

Figure 4. Nectar calendar of Bhadrak and Kendraparha districts, Orissa, India.
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Discussion and Conclusion

Most of the indigenous people are tribes who have collected honey as a livelihood for generations. Due to an absence of organized bee keeping, since 1975 these people collect and sell honey $ 0.40 per kg. Since cultivable land is scanty in this coastal area, 25% of the local tribes depend on fishing, 21% on farming and the remaining 20% of the population are wage-earning laborers in fishing, farming and forest product-related occupations while, nearly 35% people do not have any occupation [29]. Thus there is an urgent need for socioeconomic improvement of this eastern coastal region of India where three-fourths of the population lives under the poverty line [8].

Results of this work reveal that 70% of the honeys are unifloral among which 30% are from the mangrove forests. Principal Component Analysis has confirmed that all the thirty-seven unifloral honey samples have been classified correctly by the melissopalynological analysis. There is a high demand for unifloral honey in the local as well as in the global market [30]. Unifloral nature, very low HDE/P (<0.09 for most of the samples) and absence of toxic palynotaxa guarantee the suitability of these honey samples for human consumption.

Honeybees are effective and potential pollinators in agricultural and natural ecosystems in different seasons; this can enhance the crop productivity improving the overall socio-economic status of the local tribal communities. A monthly nectar calendar of all the honeybee species would educate rural beekeepers to produce unifloral honey in this region. This calendar of the study area and extensive field observations of bee pasturing in the present study reveal that during the Winter HFP, Alstonia scholaris, Brassaica nigra, Bruguiera gymnorrhiza, Coriandrum sativum, Eucalyptus globulus, Phoenix paludosa, Syzygium cumini, and Zizyphus jujuba are oil yielding plants while Acanthus ilicifolius, Aegiceras corniculatum, Avicennia marina, Bruguiera gymnorrhiza, Phoenix paludosa, Pongamia pinnata, and Sonneratia apetala are mangrove plants. Arecaaceae are represented in 29 samples followed by Myrtaceae and Fabaceae each in 22 samples and Apicaceae in 12 samples. Anacardiaceae, Rhizophoraceae and Lythraceae each in 8, Myrsinaceae 7 and Asteraceae and Sapotaceae each in 6 samples. Highest number of palynotaxa (12) is recorded in the sample Vidi-II collected from Tihidi in Bhadrak and lowest number of palynotaxa (1) in Kpra-I collected from Patakur in Kendraparha. The vegetation cover in this region is thus diverse enough to sustain bee colonies. Local vegetation plays a significant role as to which polens are collected by bees [31] and it is possible to produce several monofloral honeys in a region with great plant diversity [32].

This is the first case study of melissopalynological evaluation of apicultural entrepreneurship in India taking the coastal districts as a model. The findings of melissopalynology point to the potential commercial value of the honey market [4]. Qualitative and quantitative melissopalynological analyses in the present study demonstrate that these coastal regions are rich in bee plants with a potential of producing adequate unifloral honey, have an extended honey flow period and thus can be utilized commercially for a moderate to large-scale apicultural venture. We suggest that the best possible regions for apicultural entrepreneurship may be the areas near cultivated vegetation in Basudevpur, Bhadrak, Tihidi, Dhamnagar in Bhadrak district and Aul, Rajkanika, Patamundai, Kendraparha, Mahakalparha in Kendraparha district; the adjacent dry deciduous forests of Banta and Tihidi in Bhadrak, Nuahat, Patamundai, and Mahakalparha in Kendraparha and the mangrove forests of Dhantra and Chandbali in Bhadrak and Rajkanika, Bhitarakanika, Satavaya and Rajnagar in Kendrapara are also suitable for this venture. The competent authority, on the basis of the pollen analytical data presented in this work, should initiate apicultural enterprises in these two eastern coastal districts of India to improve the socio-economy of the local inhabitants of this region.

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Author Contributions

Conceived and designed the experiments: DU S. Bhattacharya DKF S. Bera. Performed the experiments: DU. Analyzed the data: DU DKF S. Bera. Contributed reagents/materials/analysis tools: DU S. Bera. Wrote the paper: DU DKF S. Bera.
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