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# Growth rate pattern and economic characteristics of the silkworm, *Bombyx mori* L., with medicinal plant extracts' applications

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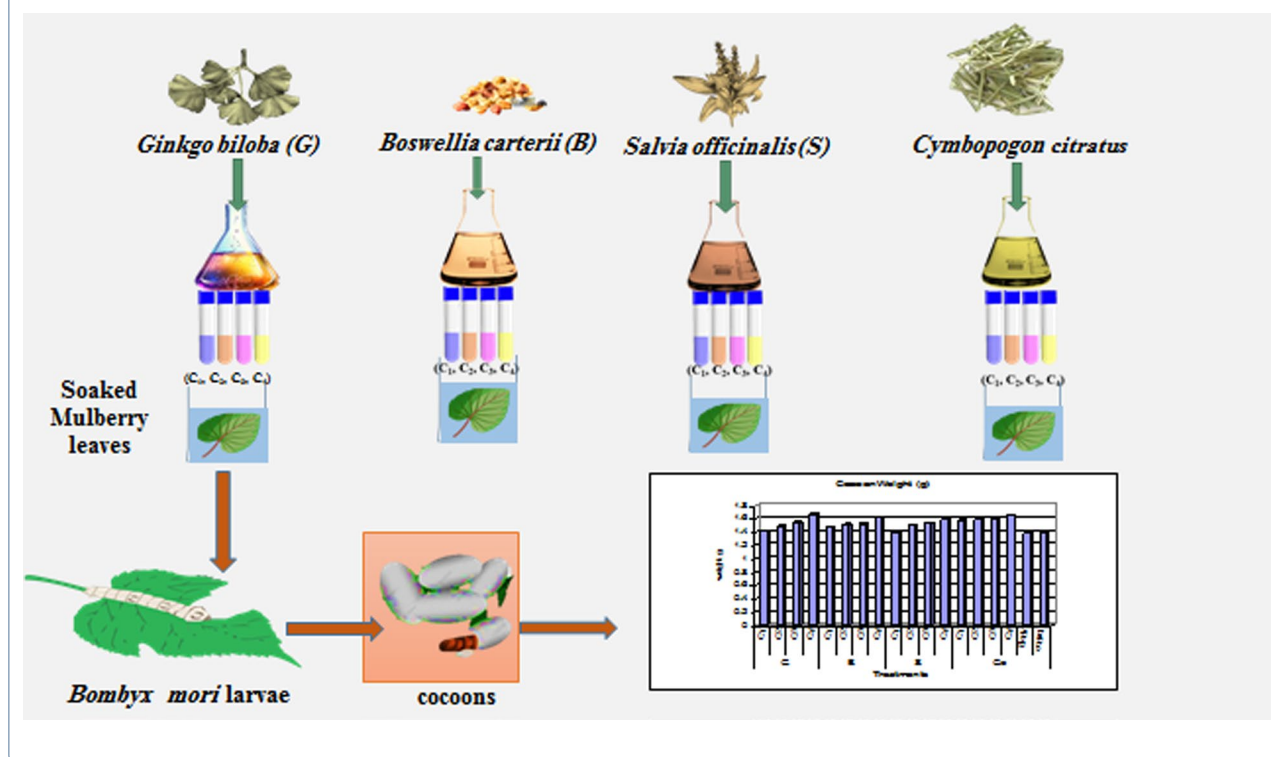
## Abstract

Among the best natural fibers, natural silk is well liked by customers worldwide. The stability of the silkworm cocoon crop makes it most viable for enhancing sericulture, which primarily depends on mulberry leaf quality. The nutritional constituents of mulberry leaves do not always meet the requirements of the silkworm larvae because more than 60% of the Egyptian rearers depend on huge mulberry trees scattered along the canals and roadsides, which are not fertilized. Medical plants have many botanical components that are useful for animals and humans. Extracts of four plant species were used: *Ginkgo biloba* (G), *Boswellia carterii* (B), *Salvia officinalis* (S), and *Cymbopogon citratus* (Cc). Extracts were used to prepare four concentrations: C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>, and C<sub>4</sub>. Seventeen silkworm traits were monitored, including fifth and whole larval duration, larval mortality for young and grown larvae, fourth and fifth growth rate, cocooning ratio, pupation percentage, percentage of double cocooning, and cocoons number per liter. Moreover, after sexing, the weight of the full cocoon, weight of the cocoon shell, pupa weight, shell percentage, and silk productivity were recorded for females and males. Also, the cocoon yield by number and weight was estimated. Plant extracts enhanced most silkworm *Bombyx mori* L. characteristics, except for double cocooning percentage. Using plant extracts improved most mulberry silkworm characteristics except for the double cocooning percentage. C<sub>3</sub> and C<sub>4</sub> concentrations yielded the best results for all traits. Extracts of *Cymbopogon citratus* (Cc), *Boswellia carterii* (B), and *Salvia officinalis* (S) yielded the highest mean for most traits. The essential oils are perhaps the reason behind the enhancement of the tested traits of silkworms. The highest concentration of C<sub>4</sub> was the best for all characters under study, so the decreased mortality percentage of silkworm larvae led to increased cocoon crops and enhanced silkworm traits quality.

**Keywords** Economic traits, Essential oils, Growth rate, *Morus alba*, Plant extracts, Silkworm *Bombyx mori*

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## Graphic Abstract



## Introduction

Larvae of the silkworm *Bombyx mori* L. are monophagous and live merely on the leaves of mulberry, which provide the necessary nutritional constituents needed for the growth and development of silkworms, including water (Ch'ng, 2022). The nutritional contents of the mulberry leaf are the primary factor that significantly influences the outgrowth and maturation of larvae and, therefore, affects the cocoons' characteristics (Marin et al. 2023). Consequently, it is essential to enhance the outcome of cocoons to develop the fineness and quantum of mulberry leaves with various ingredients, like vitamins, foliar fertilizers, vermicompost, amino acids, antibiotics, plant extracts, etc. (Chavan et al. 2024; & Mir et al. 2024; Ghazy et al. 2020; Murugesh et al. 2021; Muzamil et al. 2023; Nath et al. 2023; and Mashaal et al. 2024). Successful silkworm rearing depends on many factors, the foremost of which is that mulberry leaf, and silkworm larvae require good mulberry leaves. Mulberry leaves are grown in temperate zones; however, their quality is still poor. Leaf quality is one of the critical challenges for silkworm rearing, and poor nutrition of mulberry leaves is an essential factor that leads to a shortage of cocoon crops. The mulberry leaf quality varies depending on age, freshness, and leaf nutritional

constituents (Doliş et al. 2024). The constitution of mulberry leaves significantly influences the larval health, as they provide the essential factors for growth: water, proteins, and carbohydrates. Meanwhile, protein is vital in synthesizing silk and producing silkworm eggs. According to Sarkar (2020), there is a strong correlation between high-quality mulberry leaves and the effective rearing rates of silkworms. Consequently, any deficiencies in the nutrients of mulberry leaves can result in poor silkworm larvae development and low-quality silk output. By supplementing with additional nutrients and plant extracts, the physiological and biochemical processes in *Bombyx mori* can be activated, leading to improved larval growth, increased food consumption, and greater silk production (Thangapandian and Dharanipriya 2019; Gupta et al. 2022).

Medicinal or botanical plants are rich in botanical components that benefit the health of animals and humans, while aromatic plants produce volatile compounds known as essential oils. Essential oil is a concentrated hydrophobic liquid that tends to vaporize easily and is dubbed "essential" because it captures the essence of a plant's fragrance. Plants are a high source of organic chemicals and phytochemicals that impact

various insects (Gouda et al. 1997; Chaachouay et al. 2021).

Plants containing essential oils are important in medical and pharmaceutical aspects because the essential oils' chemical constituents are complex and may include many compounds. These compounds are used in many preparations, such as immune system, analgesic, anti-inflammatory, wound healing, anti-tumor activities, antifungal, antiviral, and antibacterial features (Sousa et al. 2023). Essential oils are found in several medicinal plants, such as *Ginkgo biloba* L. (family: Ginkgoaceae, common rubric: Ginkgo), *Salvia officinalis* L. (family: Lamiaceae, common name: Sage), *Boswellia carterii* Flueck. (family: Burseraceae, common name: resin, Luban), and *Cymbopogon citratus* (family: Gramineae, common name: Lemongrass, etc.). These plants are fortified with different kinds of natural active ingredients and have a wide scope of pharmacological activities, as adduced by Oladeji et al. (2019), Tabassum et al. (2022), Khalifa et al. (2023), and Anjali et al. (2024).

This paper discusses the effect of different nutritional modes on medical plant extracts *Ginkgo biloba* (G), *Boswellia carterii* (B), *Salvia officinalis* (S), and *Cymbopogon citratus* (Cc), affecting the growth and cocoon characters during silkworm rearing and output silkworm, *Bombyx mori* L.

## Material and methods

This experiment was conducted during the Spring rearing feast of 2023 at the Sericulture Research Department of the Plant Protection Research Institute, Agriculture Research Center in Giza, Egypt. Hybrid eggs of the silkworm, *Bombyx mori* L. (F<sub>272</sub> X D<sub>262</sub>), were obtained from the silkworm breeding program at the Sericulture Research Department (Ghazy 2007). The eggs were divided and incubated for hatching at 25 °C with 85% relative humidity.

### Preparation of plant extracts

Four species of medical plants were used to prepare extracts: *Ginkgo biloba* (G), *Boswellia carterii* (B), *Salvia officinalis* (S), and *Cymbopogon citratus* (Cc), which were collected from the local market. Four concentrations were used from previously selected plants. The specific weights of selected plants were determined for each concentration: 1 mg, 2 mg, 10 mg, and 20 mg; they were coded as C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>, and C<sub>4</sub>, respectively. They were left overnight in 1 ml of hot distilled water. Then, the extracts were filtered using Whatman papers.

### Treatment techniques for silkworm larvae

The hatched silkworm larvae were distributed into 54 plastic trays. Each tray contains 500 silkworm larvae. Mulberry fresh leaves *Morus alba* var. Canava-2 was drenched in the four prepared concentrations of all plant extracts for about 10 min. Then, the leaves were dried using an electric fan. Also, the blank treatment was applied by treating leaves with distilled water and drying them, and then offering them to larvae. Silkworm larvae fed with untreated mulberry leaves are considered the control treatment.

During the early instars of the silkworm larvae, the leaves were chopped. Polyethylene sheets were used as a base layer and cover from the first to the third instar larvae for every tray. Wet foam strips surrounded the bottom larvae (Ghazy 2008); meanwhile, the entire mulberry leaf was provided for the 4th and 5th instar larvae. Larval disinfectant, serilime, was obtained from the Sericulture Research Department and was applied during every instar as described by Hosny et al. (2002). Collapsible frames were used during the montage of matured larvae. Silkworm larvae were reared under laboratory conditions (mean temperature of 23.713 ± 0.118 and relative humidity of 59.757 ± 0.529).

### Silkworm characteristics

Data were registered for all the treatments, viz. fifth (duration of fifth larvae) and total larvae duration, mortality for young and grown larvae, fourth (4th growth rate) and fifth growth rate (5th growth rate), cocooning ratio, pupation percentage, double cocooning %, and cocoons number/liter. Moreover, after sexing (cocoon, shell, and pupa) was weighed, cocoon shell percentage and productivity of silk were recorded for both sexes. Cocoon crops as number and weight per 10,000 larvae were registered.

The percentage of dead larvae and cocooning was calculated as follows:

$$\text{Mortality (\%)} = \frac{\text{No.ofdeadlarvae}}{\text{Totalnumberoflarvae}} \times 100$$

$$\text{Cocooning percentage (\%)} = \frac{\text{No.ofcocoonsformed}}{\text{Totalnumberoflarvaekept}} \times 100$$

The pupation ratio was evaluated as follows:

$$\text{Pupation ratio (\%)} = \frac{\text{No.ofhealthypupae}}{\text{CorrectbasicNo.ofexamined}} \times 100$$

Cocoon shell ratios were studied based on the following formula

$$\text{Cocoon shell ratio} = \frac{\text{Weight of cocoon shell}}{\text{Weight of full cocoon}} \times 100$$

The collected data on the above-mentioned economic traits were analyzed according to (SAS, 1998; Smith 2024).

Cocoon crops were determined by number for 10,000 larvae as the next formulae:

$$\text{Cocoon crop as number} = \frac{\text{All number of excellent cocoons collected}}{\text{Total number of larvae reserve after 4<sup>th</sup> molt}} \times 10000$$

Growth rates were calculated according to Waldbauer (1968):

$$\text{Growth index} = \frac{\text{End weight of the larvae (g)} - \text{starting weight of the larvae (g)}}{\text{Starting weight of the larvae (g)}}$$

**Table 1** Impact of different plant extract treatments on mulberry silkworm, *Bombyx mori* L. characters

| Treatment          | Character                    |                        |                      |                |                            |                |                    |                      |
|--------------------|------------------------------|------------------------|----------------------|----------------|----------------------------|----------------|--------------------|----------------------|
|                    | Fifth larval duration (days) | Larval Duration (days) | Larval mortality (%) |                | Growth rate (g/larvae/day) |                | Cocoon crop        |                      |
|                    |                              |                        | Young instars        | Grown instars  | 4th instar                 | 5th instar     | Number (No)        | Weight (g)           |
| G                  | 8.000±0.408 c                | 30.000±0.000 c         | 1.608±0.471 d        | 9.658±0.834 c  | 0.146±0.003                | 0.082±0.002 a  | 8084.200±51.196 c  | 12,364.600±498.007 b |
| B                  | 8.827±0.041 ab               | 31.130±0.043 b         | 1.442±0.355 ab       | 7.617±0.171 c  | 0.147±0.003                | 0.069±0.002 bc | 9300.800±446.638 a | 14,272.900±903.170 a |
| S                  | 8.000±0.408 c                | 30.000±0.000 c         | 4.200±0.481 a        | 8.592±0.182 b  | 0.143±0.003                | 0.082±0.002 a  | 9352.300±124.747 a | 14,114.000±536.762 a |
| Cc                 | 8.673±0.289 bc               | 30.673±0.289 b         | 2.783±1.045 c        | 8.406±0.183 bc | 0.146±0.004                | 0.069±0.002 bc | 8833.300±75.914 b  | 14,161.400±271.591 a |
| Blank              | 9.506±0.041a                 | 32.173±0.430 a         | 5.400±0.449 bc       | 19.667±0.041 b | 0.145±0.005                | 0.070±0.002 b  | 6360.000±40.825 d  | 8784.100±4.082 c     |
| Control            | 9.506±0.082a                 | 32.173±0.041 a         | 8.333±0.408 b        | 27.733±0.082 a | 0.143±0.006                | 0.065±0.001 c  | 5780.000±81.650 e  | 7845.800±0.016 d     |
| F                  | 6.610**                      | 21.570**               | 32.540**             | 24.570**       | 0.230                      | 19.320**       | 98.690**           | 175.700**            |
| Between treatments |                              |                        |                      |                |                            |                |                    |                      |
| LSD 5%             | 0.747                        | 0.604                  | 1.310                | 4.730          | –                          | 0.005          | 440.200            | 621.800              |

| Treatment          | Character                |                    |                                 |                   |                   |                         |                  |                        |                            |
|--------------------|--------------------------|--------------------|---------------------------------|-------------------|-------------------|-------------------------|------------------|------------------------|----------------------------|
|                    | Cocooning percentage (%) | Pupation ratio (%) | Double Cocooning Percentage (%) | Cocoon/liter (No) | Cocoon weight (g) | Cocoon Shell Weight (g) | Pupae weight (g) | Cocoon shell ratio (%) | Silk productivity (cg/day) |
| G                  | 80.842±0.521 c           | 97.250±0.923 bc    | 1.483±0.638 c                   | 205.400±4.941 b   | 1.529±0.016 b     | 0.275±0.004 b           | 1.192±0.014 b    | 18.010±0.199 b         | 1.907±0.026 a              |
| B                  | 93.008±4.466 a           | 99.000±0.555 ab    | 3.775±1.431 b                   | 178.650±3.115 d   | 1.532±0.014 b     | 0.275±0.004 b           | 1.195±0.013 b    | 18.041±0.193 b         | 1.752±0.023 b              |
| S                  | 93.523±1.247 a           | 99.000±0.555 ab    | 3.459±0.426 b                   | 188.425±5.112 c   | 1.508±0.012 b     | 0.277±0.003 b           | 1.171±0.011 b    | 18.450±0.199 b         | 1.921±0.022 a              |
| Cc                 | 88.333±0.759 b           | 100.000±0.000 a    | 5.083±1.315 a                   | 179.750±3.953 d   | 1.603±0.013 a     | 0.305±0.003 a           | 1.236±0.012 a    | 19.134±0.186 a         | 1.952±0.020 a              |
| Blank              | 63.600±0.816 d           | 95.000±1.491 c     | 0.950±0.004 c                   | 212.000±0.810 ab  | 1.381±0.013 c     | 0.226±0.004 c           | 1.089±0.010 c    | 16.478±0.191 c         | 1.336±0.025 c              |
| Control            | 57.800±0.041 e           | 95.000±1.491 c     | 2.000±0.816 c                   | 215.600±0.996 a   | 1.357±0.012 c     | 0.223±0.005 c           | 1.068±0.010 c    | 16.416±0.274 c         | 1.316±0.031 c              |
| F                  | 98.69**                  | 5.830**            | 14.690**                        | 37.360**          | 57.030**          | 83.170**                | 35.040**         | 29.780**               | 177.470**                  |
| Between treatments |                          |                    |                                 |                   |                   |                         |                  |                        |                            |
| LSD 5%             | 4.402                    | 2.493              | 1.168                           | 7.489             | 0.035             | 0.010                   | 0.031            | 0.555                  | 0.062                      |

Where: Treatments (G: *Ginkgo biloba*, B: *Boswellia carterii*, S: *Salvia officinalis*, and Cc: *Cymbopogon citratus*. & (\*) significant at 0.05, (\*\*) highly significant at 0.01 & Mean ± Standard Error.

## Results and discussion

Table 1 shows the influence of different plant extract treatments on mulberry silkworm, *Bombyx mori* L., traits. Data reveal that there were highly significant differences between treatments for duration of fifth and whole larvae, mortality of larvae for young and grown instars, growth rate during the fifth instar and crop of cocoons for number and weight, cocooning percentage, pupation ratio, percentage of double cocoons, cocoons number/liter, weights of cocoon, shell, pupae, cocoon shell ratio, and productivity of silk traits. On the other hand, the differences between treatments were insignificant for the growth rate of the fourth instar. All plant extract treatments decreased the fifth duration, total larval durations, and larval mortality during young and grown instars compared with the blank and control treatments. The growth rate for the fourth and fifth instars was almost higher than the control treatment also; crop of cocoons by number and weight traits acquired the highest averages for all treatments. The same results were noticed for cocooning %, pupation ratio, cocoon numbers/liter, weight of cocoon, weight of cocoon shell, weight of pupa, cocoon shell %, and productivity of silk.

Using plant extracts improved most mulberry silkworm characteristics except for double cocooning percentage. These may be due to the presence of bioactive compounds gave the economic value and medical properties like as essential oils in tested medical plants. These outcomes match with those of Djapic et al. (2023), who noted that *Ginkgo biloba* essential oil comprises monoterpenes, oxygenated monoterpenes, sesquiterpenes, oxygenated sesquiterpenes, esters, benzopyrans, an oxolane, and a rose ketone. Caryophyllene-4(12),8(13)-dien-5 $\alpha$ -ol was the most abundant compound, followed by 14-hydroxy-(Z)-caryophyllene, caryophyllene oxide, and hydroxyl dihydroedulan. Also, Kačaniova et al. (2021), Assagaf et al. (2022), & Raal et al. (2024) stated that *Salvia officinalis* L. contains important components; about 98% from essential oils was retrieved from the leaves. It was responsible for the bactericide/bacteriostatic properties. Furthermore, Ayub et al. (2018), Perveen and Alsayed (2023), and Obisioiu et al. (2023) showed that essential oil in *Boswellia carterii* differed according to climate and region. The essential oil constituents ranged from 5 to 9%, with 65–85% soluble resins and 30–40% water-soluble gums. The oil yields ranged between 0.2 and 2.9%; there were 49 components in the essential oils. Furthermore, 5% of the total oil represented 11 main constituents: limonene,  $\beta$ -pinene, trans-thujone,  $\alpha$ -pinene, 1,8-cineole, camphor, cis-thujone,  $\alpha$ -humulene, viridiflorol, manool, and camphene, as mentioned by Lakušić et al. (2013). Furthermore,

Chaudhary et al. (2024) noted that lemon grass is widely used in medicines, foods, perfume, soap, and cosmetics due to the presence of essential oils, which gives it economic value besides medicinal use. The essential oil content reached 70–80% and varied according to geographic origin (Alvarado-García, 2023). A large number of terpenes were isolated in *Cymbopogon citratus* and limonene; among the most prevalent monoterpenes in essential oils is limonene (Schaneberg and Khan 2002). Żukowska and Durczyńska (2024) noted that essential oils are effective antibacterial agents against a variety of bacterial strains, including staphylococci, bacilli, streptococci, and mycobacteria; they harm cell membranes, impair enzymatic processes, and reduce ambient pH. High-level phenolic chemicals such as carvacrol, eugenol, and thymol have the most potent bactericidal properties, triggering cell death. So, applying the medical plant extracts with larvae of silkworms leads to physiological stimulation by active ingredients resulting in increasing larval growth which leads to increased cocoon production and silk. These results align with Hajam et al. (2024a, b) reported that adding plant extracts to the mulberry leaves leads to significant enhancement, in larval and cocoon weight, and higher resistance to diseases. Also, according to Naphade et al. (2025) it is suggested that different concentrations of extract *Annona reticulata* L. improved the economic characteristics of *B. mori* such as filament length and weight of cocoon, shell, pupa, and filament.

The impact of different concentrations of plant extracts on mulberry silkworm, *Bombyx mori* L., characteristics is found in Table 2. There were insignificant differences for fifth and total instars larvae durations, grown larval mortality, fourth and fifth growth rate, and pupation ratio. The significant differences were observed for young larval mortality, cocoon yield by number. Highly significant differences were detected for cocooning percentage, double cocooning ratio, cocoon number per liter, cocoon weight, shell weight, pupa weight, shell ratio, and silk productivity. In general, concentrations C<sub>3</sub> and C<sub>4</sub> earned the best results for all examined parameters. Plant extracts' ingredient compounds such essential oils are perhaps the reason of enhancement most of the tested traits. These data align with Bajpai et al. (2015), Rashan et al. (2019), and Abdelkader et al. (2023), who found essential oils in plant extracts of *Ginkgo biloba*, *Salvia officinalis*, *Boswellia carterii*, and *Cymbopogon citratus*, respectively. Also, Singh et al. (2014) reported that the economic characteristics of the silkworm were enhanced by applying the *Aloe vera* essential oil. In addition, Barge and Pardeshi (2024) proved that *Sida acuta* plant extract supplemented at (0.5, 1.0, 1.5, 2.0, and 2.5%) to IV instars larvae of *Bombyx mori* enhanced cocoon characteristics; phytoecdysteroid

**Table 2** Impact of different plant extract concentrations on mulberry silkworm, *Bombyx mori* L. characters

| Treatment                     | Character                    |                        |                                 |                   |                            |                         |                    |                        |                            |
|-------------------------------|------------------------------|------------------------|---------------------------------|-------------------|----------------------------|-------------------------|--------------------|------------------------|----------------------------|
|                               | Fifth larval duration (days) | Larval duration (days) | Larval mortality (%)            |                   | Growth rate (g/larvae/day) |                         | Cocoon Crop        |                        |                            |
|                               |                              |                        | Young Instars                   | Grown Instars     | 4th instar                 | 5th instar              | Number (No)        | Weight (g)             |                            |
| C <sub>1</sub>                | 8.669±0.263                  | 30.920±0.281           | 2.898±0.753 b                   | 13.200±2.164      | 0.143±0.003                | 0.074±0.001             | 7624.400±319.413 b | 11,008.400±492.145 c   |                            |
| C <sub>2</sub>                | 8.669±0.263                  | 30.949±0.270           | 4.113±0.663 a                   | 13.294±2.164      | 0.146±0.003                | 0.074±0.001             | 7996.700±365.065 a | 11,853.500±599.824 b   |                            |
| C <sub>3</sub>                | 8.835±0.203                  | 31.115±0.257           | 4.389±0.618 a                   | 13.856±2.072      | 0.145±0.003                | 0.072±0.001             | 8055.000±375.365 a | 12,116.700±638.095 b   |                            |
| C <sub>4</sub>                | 8.835±0.219                  | 31.115±0.257           | 4.444±0.684 a                   | 14.098±2.240      | 0.146±0.003                | 0.071±0.001             | 8130.900±387.353 a | 12,716.600±734.088 a   |                            |
| F Between Con-<br>centrations | 0.200                        | 0.370                  | 3.700*                          | 0.100             | 0.110                      | 1.070                   | 3.170*             | 15.780**               |                            |
| LSD 5%                        | –                            | –                      | 1.069                           | –                 | –                          | –                       | 359.400            | 507.700                |                            |
| Treatmentnt                   | Character                    |                        |                                 |                   |                            |                         |                    |                        |                            |
|                               | Cocooning percentage (%)     | Pupation ratio (%)     | Double cocooning percentage (%) | Cocoon/Liter (No) | Cocoon Weight (g)          | Cocoon Shell weight (g) | Pupae weight (g)   | Cocoon Shell ratio (%) | Silk productivity (cg/day) |
| C <sub>1</sub>                | 76.244±3.194 b               | 97.500±0.737           | 3.025±0.565 ab                  | 200.067±3.767 b   | 1.437±0.011 c              | 0.246±0.003 c           | 1.128±0.010 c      | 17.171±0.179 c         | 1.594±0.021 c              |
| C <sub>2</sub>                | 79.967±3.651 a               | 97.500±0.737           | 2.147±0.418 b                   | 199.967±2.506 a   | 1.470±0.012 b              | 0.259±0.003 b           | 1.148±0.010 bc     | 17.657±0.186 b         | 1.697±0.023 b              |
| C <sub>3</sub>                | 80.550±3.754 a               | 97.500±0.737           | 2.147±0.243 b                   | 197.217±2.824 a   | 1.490±0.011 b              | 0.266±0.003 b           | 1.160±0.009 b      | 17.8976±0.164 ab       | 1.697±0.020 b              |
| C <sub>4</sub>                | 81.309±3.874 a               | 97.667±0.765           | 3.847±0.804 a                   | 189.300±3.332 b   | 1.543±0.011 a              | 0.282±0.003 a           | 1.199±0.010 a      | 18.293±0.164 a         | 1.801±0.021 a              |
| F Between Con-<br>centrations | 3.170*                       | 0.010                  | 5.920**                         | 5.330**           | 18.660**                   | 28.080**                | 10.850**           | 8.260**                | 21.630**                   |
| LSD 5%                        | 3.594                        | –                      | 0.954                           | 6.115             | 0.029                      | 0.008                   | 0.025              | 0.453                  | 0.050                      |

Where: Concentrations: (C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>, and C<sub>4</sub>) & (\*) significant at 0.05, (\*\*) highly significant at 0.01 & Mean ± Standard Error.

of *Sida acuta* has growth-enhanced impact in silkworm which helps to raise the cocoon production.

Table 3 shows the impact of different plant extracts between the interactions among treatments and concentrations on the mulberry silkworm, *Bombyx mori* L., characteristics. The characters of fifth and total larvae durations, mortality of larvae during the fourth and fifth instars, growth rate, crop of cocoons by number, cocooning %, pupation ratio, and cocoon shell ratio showed insignificant differences. On the other hand, there was high significance in the crop of cocoons by weight, double cocooning percentage, cocoon number/liter, cocoon weight, shell weight, pupa weight, and productivity of silk. All concentrations of tested plant extract treatments acquired better results, compared with blank and control treatments. The heights concentration C<sub>4</sub> has the best averages for all characteristics with all treatments. Concentration C<sub>4</sub> from plant extracts G, Cc, S, and B was better averaged for all traits under study. This may be due to the amount of vital compounds such as essential oil in the plant extracts for *Ginkgo biloba*, *Salvia officinalis*,

*Boswellia carterii*, and *Cymbopogon citratus*. The obtained data confirm with those found by Manimuthu and Isaiarasu (2010) as they proved that supplementation of *Aloe vera* enhances the development and cocoon characteristics of the mulberry silkworm, *Bombyx mori* L., 2.0% concentration increased larvae weight, growth index, effective rearing rate, larvae consumption index, weight of cocoon, pupa weight, and fibroin content. Also, Manjunath et al. (2020a) proved that the application of medical plant (*Asparagus officinalis*) at (CSR<sub>2</sub> and PM x CSR<sub>2</sub>) silkworm larvae was found influential by consolidating the larval growth characters, 5th larval duration, larval weight, and reduced larval mortality.

The impacts of different plant extracts in the interactions between treatments and sexes on the mulberry silkworm, *Bombyx mori* L., characteristics are listed in Table 4. High significance was detected in the interactions between treatments and sexes for cocoon weight, pupa weight, and cocoon shell ratio, whereas insignificant differences were detected for shell weight and silk productivity characteristics. Generally, females and males

**Table 3** Impact of different plant extracts of the interactions between treatments and concentrations on the mulberry silkworm, *Bombyx mori* L. characters

| Treatment                          | Character                    |                        | Larval mortality (%) |             |               |             | Growth Rate (g/larvae/day) |                  | Cocoon Crop        |            |
|------------------------------------|------------------------------|------------------------|----------------------|-------------|---------------|-------------|----------------------------|------------------|--------------------|------------|
|                                    | Fifth larval duration (days) | Larval duration (days) | Young instars        |             | Grown instars |             | 4th instar                 | 5th instar       | Number (No)        | Weight (g) |
|                                    |                              |                        |                      |             |               |             |                            |                  |                    |            |
| G                                  | C <sub>1</sub>               | 8.000±0.577            | 30.000±0.577         | 0.200±0.058 | 8.000±1.856   | 0.144±0.006 | 0.080±0.004                | 7980.000±577.350 | 11.339.420±820.403 |            |
|                                    | C <sub>2</sub>               | 8.000±0.577            | 30.000±0.577         | 2.000±0.577 | 8.467±3.844   | 0.147±0.005 | 0.083±0.003                | 8013.333±38.3442 | 11.904.368±57.108  |            |
|                                    | C <sub>3</sub>               | 8.000±0.577            | 30.000±0.577         | 2.067±0.577 | 10.833±1.364  | 0.146±0.003 | 0.083±0.003                | 8160.000±100.000 | 12.554.973±153.860 |            |
|                                    | C <sub>4</sub>               | 8.000±0.577            | 30.000±0.577         | 2.167±0.577 | 11.333±1.528  | 0.145±0.006 | 0.080±0.003                | 8183.333±3.333   | 13.659.620±853.711 |            |
| B                                  | C <sub>1</sub>               | 8.827±1.155            | 31.000±0.577         | 0.456±0.00  | 7.267±1.732   | 0.146±0.005 | 0.073±0.003                | 7980.000±577.350 | 11.799.787±47.985  |            |
|                                    | C <sub>2</sub>               | 8.827±1.155            | 31.173±0.0001        | 2.114±882   | 7.467±3.283   | 0.146±0.006 | 0.070±0.004                | 9626.667±31.798  | 14.527.218±424.046 |            |
|                                    | C <sub>3</sub>               | 8.827±1.155            | 31.173±0.058         | 1.467±0.00  | 7.667±4.055   | 0.146±0.006 | 0.067±0.003                | 9643.333±278.827 | 14.665.774±28.529  |            |
|                                    | C <sub>4</sub>               | 8.827±1.155            | 31.173±0.012         | 1.733±441   | 8.067±0.833   | 0.151±0.008 | 0.066±0.003                | 9953.333±17.638  | 16.099.019±16.215  |            |
| S                                  | C <sub>1</sub>               | 8.000±0.577            | 30.000±0.577         | 2.800±1.764 | 8.533±2.717   | 0.142±0.006 | 0.082±0.004                | 8980.000±11.547  | 12.610.614±8.662   |            |
|                                    | C <sub>2</sub>               | 8.000±0.577            | 30.000±0.577         | 4.833±0.882 | 8.100±0.882   | 0.143±0.007 | 0.081±0.004                | 9440.000±5.774   | 14.162.294±94.866  |            |
|                                    | C <sub>3</sub>               | 8.000±0.577            | 30.000±0.577         | 4.333±0.367 | 8.833±1.017   | 0.142±0.004 | 0.082±0.004                | 9493.333±61.734  | 14.588.310±94.866  |            |
|                                    | C <sub>4</sub>               | 8.000±0.577            | 30.000±0.577         | 4.833±2.517 | 8.900±0.729   | 0.142±0.006 | 0.082±0.003                | 9495.667±4.333   | 15.094.692±94.866  |            |
| Cc                                 | C <sub>1</sub>               | 8.173±0.01             | 30.173±0.577         | 0.200±0.058 | 8.000±1.333   | 0.142±0.007 | 0.074±0.004                | 8666.667±333.333 | 13.670.800±94.866  |            |
|                                    | C <sub>2</sub>               | 8.173±0.01             | 30.173±0.577         | 2.000±0.577 | 8.333±7.572   | 0.151±0.007 | 0.073±0.003                | 8760.000±5.774   | 13.897.127±94.866  |            |
|                                    | C <sub>3</sub>               | 9.173±0.01             | 31.173±0.577         | 4.733±0.617 | 8.400±2.333   | 0.145±0.006 | 0.066±0.004                | 8893.333±283.862 | 14.261.260±94.866  |            |
|                                    | C <sub>4</sub>               | 9.173±0.01             | 31.173±0.577         | 4.200±0.551 | 8.889±0.333   | 0.148±0.008 | 0.064±0.003                | 9013.333±33.333  | 14.816.298±94.866  |            |
| Blank                              | W                            | 9.506±0.343            | 32.173±0.000         | 5.400±2.848 | 19.667±5.696  | 0.145±0.009 | 0.010±0.003                | 6360.000±57.753  | 8784.050±94.866    |            |
| Control                            |                              | 9.506±0.343            | 32.173±0.000         | 8.333±1.155 | 27.733±3.383  | 0.143±0.011 | 0.065±0.002                | 5780.000±577.350 | 7845.847±94.866    |            |
| F Treatments X Con-<br>centrations |                              | 0.200                  | 0.300                | 0.830       | 0.040         | 0.060       | 0.540                      | 1.230            | 2.720**            |            |
| LSD 5%                             |                              | —                      | —                    | —           | —             | —           | —                          | —                | 1243.500           |            |

| Treatment      | Character                |                    | Cocoon/liter (No)               |                   |                   |                         | Cocoon weight (g) |                        | Cocoon shell weight (g) |                        | Pupae weight (g)           |                        | Cocoon shell ratio (%) |                        | Silk productivity (cg/day) |  |
|----------------|--------------------------|--------------------|---------------------------------|-------------------|-------------------|-------------------------|-------------------|------------------------|-------------------------|------------------------|----------------------------|------------------------|------------------------|------------------------|----------------------------|--|
|                | Cocooning percentage (%) | Pupation ratio (%) | Double cocooning percentage (%) | Cocoon/liter (No) | Cocoon weight (g) | Cocoon shell weight (g) | Pupae weight (g)  | Cocoon shell ratio (%) | Pupae weight (g)        | Cocoon shell ratio (%) | Silk productivity (cg/day) | Cocoon shell ratio (%) | Pupae weight (g)       | Cocoon shell ratio (%) | Silk productivity (cg/day) |  |
|                |                          |                    |                                 |                   |                   |                         |                   |                        |                         |                        |                            |                        |                        |                        |                            |  |
| G              | C <sub>1</sub>           | 79.800±5.77        | 97.000±1.528                    | 0.600±0.058       | 235.200±5.987     | 1.421±0.024             | 0.235±0.005       | 1.126±0.022            | 16.602±2.143            | 1.629±0.038            |                            |                        |                        |                        |                            |  |
|                | C <sub>2</sub>           | 80.133±0.384       | 97.000±1.528                    | 0.667±0.012       | 216.000±4.382     | 1.486±0.038             | 0.264±0.010       | 1.160±0.032            | 17.878±2.308            | 1.832±0.067            |                            |                        |                        |                        |                            |  |
|                | C <sub>3</sub>           | 81.600±1.000       | 97.000±1.528                    | 1.333±0.577       | 200.000±2.921     | 1.541±0.023             | 0.284±0.007       | 1.191±0.021            | 18.493±2.387            | 1.975±0.050            |                            |                        |                        |                        |                            |  |
|                | C <sub>4</sub>           | 81.833±0.033       | 98.000±2.000                    | 3.333±0.115       | 170.400±1.809     | 1.669±0.031             | 0.316±0.006       | 1.292±0.028            | 19.068±2.462            | 2.193±0.042            |                            |                        |                        |                        |                            |  |
| B              | C <sub>1</sub>           | 79.800±5.774       | 99.000±1.000                    | 7.300±0.173       | 175.200±7.419     | 1.479±0.031             | 0.261±0.009       | 1.156±0.027            | 17.685±2.283            | 1.641±0.054            |                            |                        |                        |                        |                            |  |
|                | C <sub>2</sub>           | 96.267±0.318       | 99.000±1.000                    | 0.600±0.173       | 185.000±3.783     | 1.509±0.028             | 0.269±0.007       | 1.178±0.025            | 17.906±2.312            | 1.778±0.050            |                            |                        |                        |                        |                            |  |
|                | C <sub>3</sub>           | 96.433±2.788       | 99.000±1.000                    | 2.600±0.173       | 184.800±3.415     | 1.521±0.028             | 0.274±0.006       | 1.185±0.025            | 18.157±2.344            | 1.724±0.036            |                            |                        |                        |                        |                            |  |
|                | C <sub>4</sub>           | 99.533±0.176       | 99.000±1.000                    | 4.600±2.309       | 169.600±5.102     | 1.618±0.025             | 0.296±0.005       | 1.260±0.023            | 18.417±2.378            | 1.864±0.034            |                            |                        |                        |                        |                            |  |
| C <sub>1</sub> | 89.800±0.115             | 99.000±1.000       | 3.300±0.115                     | 173.600±4.888     | 1.404±0.023       | 0.251±0.006             | 1.091±0.021       | 17.967±2.319           | 1.744±0.045             |                        |                            |                        |                        |                        |                            |  |

**Table 3** (continued)

| Treatment                   | Character |                | Cocooning percentage (%) | Pupation ratio (%) | Double cocooning percentage (%) | Cocoon/liter (No) | Cocoon weight (g) | Cocoon shell weight (g) | Pupae weight (g) | Cocoon shell ratio (%) | Silk productivity (cg/day) |
|-----------------------------|-----------|----------------|--------------------------|--------------------|---------------------------------|-------------------|-------------------|-------------------------|------------------|------------------------|----------------------------|
|                             |           |                |                          |                    |                                 |                   |                   |                         |                  |                        |                            |
| S                           |           | C <sub>2</sub> | 94.400±0.058             | 99.000±1.000       | 4.667±0.006                     | 193.600±4.815     | 1.500±0.024       | 0.271±0.005             | 1.167±0.021      | 18.270±2.359           | 1.885±0.038                |
|                             |           | C <sub>3</sub> | 94.933±0.617             | 99.000±1.000       | 2.667±0.006                     | 193.500±11.311    | 1.537±0.027       | 0.284±0.006             | 1.192±0.024      | 18.553±2.395           | 1.971±0.045                |
|                             |           | C <sub>4</sub> | 94.957±0.043             | 99.000±1.000       | 3.200±2.052                     | 193.000±11.494    | 1.590±0.017       | 0.300±0.005             | 1.233±0.024      | 19.010±2.454           | 2.084±0.035                |
|                             | Cc        |                | C <sub>1</sub>           | 86.667±3.333       | 100.000±0.000                   | 4.000±0.577       | 188.800±9.885     | 1.577±0.031             | 0.280±0.007      | 1.236±0.018            | 17.877±2.308               |
|                             |           | C <sub>2</sub> | 87.600±0.058             | 100.000±0.000      | 4.000±0.577                     | 177.600±5.315     | 1.586±0.023       | 0.299±0.006             | 1.223±0.028      | 18.997±2.453           | 2.034±0.041                |
|                             |           | C <sub>3</sub> | 88.933±2.839             | 100.000±0.000      | 3.333±0.058                     | 177.400±5.933     | 1.604±0.024       | 0.307±0.005             | 1.237±0.023      | 19.289±2.490           | 1.860±0.030                |
|                             |           | C <sub>4</sub> | 90.133±0.333             | 100.000±0.000      | 9.000±1.732                     | 175.200±5.426     | 1.644±0.028       | 0.333±0.006             | 1.249±0.023      | 20.372±2.630           | 2.014±0.036                |
| Blank                       |           | W              | 63.600±0.577             | 95.000±2.687       | 0.950±0.202                     | 212.000±1.461     | 1.381±0.027       | 0.226±0.007             | 1.089±0.025      | 16.478±2.127           | 1.336±0.043                |
| Control                     |           |                | 95.000±2.687             | 2.000±0.770        | 215.600±1.796                   | 1.381±0.028       | 0.226±0.008       | 1.068±0.024             | 16.416±2.119     | 1.316±0.049            |                            |
| F                           |           |                |                          |                    |                                 |                   |                   |                         |                  |                        |                            |
| Treatments X Concentrations |           | 1.230          | 0.010                    | 3.990**            | 5.470**                         | 3.050**           | 3.700**           | 2.220**                 | 1.430            | 5.090**                |                            |
| LSD 5%                      |           | –              | –                        | 2.336              | 14.979                          | 0.076             | 0.020             | 0.068                   | –                | 0.123                  |                            |

Where: Treatments (G: *Ginkgo biloba*, B: *Boswellia carterii*, S: *Salvia officinalis*, and Cc: *Cymbopogon citratus* W: distilled water; Concentrations: (C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>, and C<sub>4</sub>) & (\*) significant at 0.05, (\*\*\*) highly significant at 0.01&

Where: Treatments (G: *Ginkgo biloba*, B: *Boswellia carterii*, S: *Salvia officinalis*, and Cc: *Cymbopogon citratus*, W: distilled water; Concentrations: (C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>, and C<sub>4</sub>) & (\*) significant at 0.05, (\*\*) highly significant at 0.01 & Mean ± Standard Error.

**Table 4** Impact of different plant extracts of the interactions between Treatments and Sex on the mulberry silkworm, *Bombyx mori* L. characters

| Treatment            | Character         |             |                         |             |                  |             |                        |              |
|----------------------|-------------------|-------------|-------------------------|-------------|------------------|-------------|------------------------|--------------|
|                      | Cocoon weight (g) |             | Cocoon shell weight (g) |             | Pupae weight (g) |             | Cocoon shell ratio (%) |              |
|                      | Female            | Male        | Female                  | Male        | Female           | Male        | Female                 | Male         |
| G                    | 1.614±0.023       | 1.444±0.019 | 0.276±0.006             | 0.273±0.005 | 1.276±0.019      | 1.108±0.015 | 17.128±0.345           | 18.892±0.239 |
| B                    | 1.642±0.019       | 1.421±0.016 | 0.273±0.005             | 0.277±0.005 | 1.307±0.016      | 1.082±0.013 | 16.638±0.244           | 19.445±0.250 |
| S                    | 1.580±0.018       | 1.436±0.014 | 0.265±0.004             | 0.288±0.004 | 1.254±0.016      | 1.087±0.012 | 16.826±0.217           | 20.074±0.256 |
| Cc                   | 1.720±0.017       | 1.486±0.015 | 0.304±0.005             | 0.305±0.004 | 1.353±0.015      | 1.119±0.012 | 17.720±0.250           | 20.547±0.213 |
| Blank                | 1.395±0.021       | 1.368±0.018 | 0.227±0.005             | 0.225±0.005 | 1.098±0.017      | 1.081±0.019 | 16.189±0.210           | 16.766±0.409 |
| Control              | 1.388±0.022       | 1.327±0.017 | 0.221±0.006             | 0.225±0.006 | 1.097±0.018      | 1.040±0.016 | 15.871±0.320           | 16.961±0.372 |
| F between sex        | 190.880**         |             | 2.130                   |             | 254.580**        |             | 157.950**              |              |
| F (Treatments X Sex) | 11.050**          |             | 1.790                   |             | 16.120**         |             | 7.240**                |              |
| LSD 5%               | 0.039             |             | –                       |             | 0.034            |             | 0.586                  |              |

Where: Treatments (G: *Ginkgo biloba*, B: *Boswellia carterii*, S: *Salvia officinalis*, and Cc: *Cymbopogon citratus*. & (\*) significant at 0.05, (\*\*) highly significant at 0.01& Mean ± Standard Error

**Table 5** Impact of different plant extracts of the interactions between concentrations and Sex on the mulberry silkworm, *Bombyx mori* L. characters

| Treatment                | Character         |             |                         |             |                  |             |                        |              |
|--------------------------|-------------------|-------------|-------------------------|-------------|------------------|-------------|------------------------|--------------|
|                          | Cocoon weight (g) |             | Cocoon shell weight (g) |             | Pupae weight (g) |             | Cocoon shell ratio (%) |              |
|                          | Female            | Male        | Female                  | Male        | Female           | Male        | Female                 | Male         |
| C <sub>1</sub>           | 1.508±0.018       | 1.365±0.014 | 0.244±0.004             | 0.248±0.004 | 1.201±0.015      | 1.055±0.013 | 16.105±0.216           | 18.237±0.261 |
| C <sub>2</sub>           | 1.5426±0.019      | 1.397±0.014 | 0.257±0.005             | 0.260±0.004 | 1.221±0.016      | 1.074±0.012 | 16.682±0.262           | 18.633±0.259 |
| C <sub>3</sub>           | 1.559±0.018       | 1.421±0.013 | 0.265±0.005             | 0.268±0.004 | 1.229±0.015      | 1.092±0.012 | 16.947±0.212           | 18.848±0.261 |
| C <sub>4</sub>           | 1.615±0.019       | 1.471±0.014 | 0.279±0.005             | 0.286±0.005 | 1.274±0.016      | 1.123±0.012 | 17.181±0.191           | 19.406±0.278 |
| F (Concentrations X Sex) | 0.030             |             | 0.130                   |             | 0.110            |             | 0.220                  |              |
| LSD 5%                   | –                 |             | –                       |             | –                |             | –                      |              |

Where: Concentrations: (C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>, and C<sub>4</sub>) & (\*) significant at 0.05, (\*\*) highly significant at 0.01 & Mean ± Standard Error

**Table 6** Impact of different plant extracts of the interactions between Treatments, concentrations, and Sex on the mulberry silkworm, *Bombyx mori* L. characters

| Treatment                           | Character      | Silk productivity (cg/day) |             |             |             |                         |             |              |              |                  |             |      |  |                        |  |      |  |                            |  |      |  |
|-------------------------------------|----------------|----------------------------|-------------|-------------|-------------|-------------------------|-------------|--------------|--------------|------------------|-------------|------|--|------------------------|--|------|--|----------------------------|--|------|--|
|                                     |                | Cocoon weight (g)          |             |             |             | Cocoon shell weight (g) |             |              |              | Pupae weight (g) |             |      |  | Cocoon shell ratio (%) |  |      |  | Silk productivity (cg/day) |  |      |  |
|                                     |                | Female                     |             | Male        |             | Female                  |             | Male         |              | Female           |             | Male |  | Female                 |  | Male |  | Female                     |  | Male |  |
| G                                   | C <sub>1</sub> | 1.518±0.030                | 1.324±0.029 | 0.233±0.009 | 0.236±0.006 | 1.226±0.023             | 1.027±0.027 | 15.252±0.415 | 17.9520.436± | 1.617±0.063      | 1.641±0.043 |      |  |                        |  |      |  |                            |  |      |  |
|                                     | C <sub>2</sub> | 1.556±0.063                | 1.415±0.039 | 0.260±0.016 | 0.267±0.011 | 1.234±0.053             | 1.086±0.031 | 16.963±1.001 | 18.792±0.363 | 1.807±0.111      | 1.857±0.076 |      |  |                        |  |      |  |                            |  |      |  |
|                                     | C <sub>3</sub> | 1.582±0.031                | 1.500±0.034 | 0.285±0.010 | 0.283±0.010 | 1.231±0.029             | 1.149±0.028 | 18.108±0.660 | 18.878±0.476 | 1.982±0.072      | 1.968±0.070 |      |  |                        |  |      |  |                            |  |      |  |
|                                     | C <sub>4</sub> | 1.801±0.038                | 1.537±0.035 | 0.327±0.008 | 0.305±0.008 | 1.413±0.034             | 1.170±0.031 | 18.189±0.386 | 19.947±0.565 | 2.268±0.057      | 2.117±0.059 |      |  |                        |  |      |  |                            |  |      |  |
| B                                   | C <sub>1</sub> | 1.584±0.047                | 1.373±0.031 | 0.259±0.013 | 0.262±0.012 | 1.263±0.040             | 1.049±0.025 | 16.371±0.645 | 18.999±0.614 | 1.632±0.080      | 1.649±0.073 |      |  |                        |  |      |  |                            |  |      |  |
|                                     | C <sub>2</sub> | 1.630±0.034                | 1.388±0.033 | 0.270±0.011 | 0.268±0.010 | 1.298±0.029             | 1.058±0.028 | 16.517±0.522 | 19.294±0.546 | 1.701±0.071      | 1.859±0.069 |      |  |                        |  |      |  |                            |  |      |  |
|                                     | C <sub>3</sub> | 1.640±0.036                | 1.402±0.030 | 0.272±0.008 | 0.276±0.008 | 1.306±0.032             | 1.063±0.024 | 16.600±0.446 | 19.713±0.374 | 1.709±0.052      | 1.740±0.050 |      |  |                        |  |      |  |                            |  |      |  |
|                                     | C <sub>4</sub> | 1.715±0.032                | 1.520±0.029 | 0.292±0.007 | 0.300±0.009 | 1.362±0.027             | 1.158±0.025 | 17.063±0.283 | 19.771±0.445 | 1.838±0.041      | 1.889±0.054 |      |  |                        |  |      |  |                            |  |      |  |
| S                                   | C <sub>1</sub> | 1.474±0.033                | 1.335±0.026 | 0.242±0.008 | 0.260±0.010 | 1.170±0.030             | 1.013±0.023 | 16.442±0.446 | 19.491±0.567 | 1.680±0.058      | 1.807±0.068 |      |  |                        |  |      |  |                            |  |      |  |
|                                     | C <sub>2</sub> | 1.582±0.035                | 1.419±0.028 | 0.262±0.006 | 0.281±0.009 | 1.257±0.033             | 1.076±0.026 | 16.373±0.406 | 19.868±0.553 | 1.819±0.044      | 1.950±0.060 |      |  |                        |  |      |  |                            |  |      |  |
|                                     | C <sub>3</sub> | 1.625±0.042                | 1.449±0.024 | 0.276±0.011 | 0.292±0.007 | 1.287±0.033             | 1.098±0.023 | 16.882±0.367 | 20.224±0.500 | 1.915±0.075      | 2.027±0.050 |      |  |                        |  |      |  |                            |  |      |  |
|                                     | C <sub>4</sub> | 1.636±0.028                | 1.543±0.018 | 0.282±0.007 | 0.319±0.005 | 1.304±0.027             | 1.163±0.018 | 17.307±0.509 | 20.713±0.408 | 1.956±0.050      | 1.905±0.035 |      |  |                        |  |      |  |                            |  |      |  |
| Cc                                  | C <sub>1</sub> | 1.691±0.035                | 1.463±0.042 | 0.279±0.010 | 0.280±0.008 | 1.350±0.031             | 1.121±0.036 | 16.504±0.553 | 19.250±0.362 | 1.898±0.071      | 1.905±0.056 |      |  |                        |  |      |  |                            |  |      |  |
|                                     | C <sub>2</sub> | 1.705±0.027                | 1.468±0.022 | 0.303±0.010 | 0.295±0.006 | 1.340±0.028             | 1.106±0.020 | 17.887±0.648 | 20.117±0.371 | 2.065±0.071      | 2.003±0.041 |      |  |                        |  |      |  |                            |  |      |  |
|                                     | C <sub>3</sub> | 1.725±0.032                | 1.482±0.042 | 0.310±0.007 | 0.304±0.007 | 1.353±0.029             | 1.121±0.018 | 18.031±0.380 | 20.546±0.433 | 1.876±0.040      | 1.844±0.045 |      |  |                        |  |      |  |                            |  |      |  |
|                                     | C <sub>4</sub> | 1.757±0.036                | 1.531±0.042 | 0.324±0.008 | 0.341±0.008 | 1.371±0.032             | 1.128±0.024 | 18.467±0.282 | 22.276±0.351 | 1.963±0.050      | 2.065±0.051 |      |  |                        |  |      |  |                            |  |      |  |
| Blank                               | W              | 1.395±0.036                | 1.368±0.042 | 0.227±0.010 | 0.225±0.011 | 1.098±0.034             | 1.081±0.038 | 16.189±0.425 | 16.766±0.828 | 1.327±0.060      | 1.346±0.063 |      |  |                        |  |      |  |                            |  |      |  |
| Control                             |                | 1.338±0.044                | 1.327±0.035 | 0.221±0.011 | 0.225±0.012 | 1.097±0.036             | 1.040±0.032 | 15.871±0.649 | 16.961±0.753 | 1.294±0.060      | 1.337±0.060 |      |  |                        |  |      |  |                            |  |      |  |
| F (Treatments Concentrations X Sex) |                | 3.220**                    |             | 0.740       |             | 4.450**                 |             | 2.050        |              | 0.890            |             |      |  |                        |  |      |  |                            |  |      |  |
| LSD 5%                              |                | 0.076                      |             | —           |             | 0.068                   |             | —            |              | —                |             |      |  |                        |  |      |  |                            |  |      |  |

Where: Treatments (G: *Ginkgo biloba*, B: *Boswellia carterii*, S: *Salvia officinalis*, and Cc: *Cymbopogon citratus*. W: distilled water; Concentrations: (C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>, and C<sub>4</sub>) & (\*) significant at 0.05, (\*\*) highly significant at 0.01 & Mean ± Standard Error

Where: Treatments (G: *Ginkgo biloba*, B: *Boswellia carterii*, S: *Salvia officinalis*, and Cc: *Cymbopogon citratus*. W: distilled water; Concentrations: (C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>, and C<sub>4</sub>) & (\*) significant at 0.05, (\*\*) highly significant at 0.01 & Mean ± Standard Error

of all plant extract treatments have better results than females and males of blank and control treatments. HL (*Cymbopogon citratus*) treatment has best results regarding cocoon weight, shell weight, pupal weight, cocoon shell ratio, and silk productivity characteristics. The present study aligns with previous findings indicating that plant extracts can significantly affect larval growth and cocoon production as obtained by Swarnlata and Hassan (2023) reported that feeding silkworm larvae with mulberry leaves fortified with giloy plant extract at 3% concentration gave better results for larval growth, development, and economic characteristics. Thus, herbal treatments have stimulated the growth of silkworms, which contributes to improving silk's economic properties. Also, Lalmuankimi et al. (2020) all plant extracts gave a significant result at the concentration of 10% in larval weight, effective rate of rearing, larval mortality, and silk gland weight. So, the treatment with *Mikania micrantha*, *Murraya koenigii*, and *Pongamia glabra* has a growth raising on silkworms leading to qualities of silk based on treatment concentration.

Table 5 represents the direct impact of different plant extracts in the interactions between concentrations and sexes of the mulberry silkworm, *Bombyx mori* L. characteristics. Insignificant differences were observed for cocoon weight, shell weight, pupal weight, shell ratio, and productivity of silk for two sexes. Despite the insignificance, C<sub>4</sub> concentration was the highest for both sexes. These results agreed with those found by Hajam et al. (2024b); they reported that applying *Aloe vera*, *Ocimum sanctum*, and *Withania somnifera* plant extracts enhanced silk characters. Higher concentration promoted the length of silk filament, raw silk ratio, and other economic characters, whereas adding the plant extracts could be suggested to silkworm rears to obtain superior silk output.

The impact of different plant extracts in the interactions among treatments, concentrations, and sexes of the mulberry silkworm, *Bombyx mori* L., characteristics is shown in Table 6. High significance was noted for cocoon weight and pupae weight, while insignificance was shown for cocoon shell weight, cocoon shell ratio, and productivity of silk characters. The C<sub>4</sub> concentration was superior for former traits among all concentrations; the highest concentration of *Ginkgo biloba* (G) treatment was better for both sexes. These results coincide with those found by Manjunath et al. (2020b) who studied the effect of nine different medicinal plant extracts on cocoon and post-cocoon character of silkworm *B. mori*; among nine medicinal plant extracts, *Asparagus officinalis* administration was found effective by increasing the cocoon quality characters, viz. cocoon, shell, and pupa weight, cocoon shell ratio, silk filament length, and filament size.

## Conclusion

Using medical plant extracts of *Ginkgo biloba* (G), *Boswellia carterii* (B), *Salvia officinalis* (S), and *Cymbopogon citratus* (Cc) with four concentrations on mulberry silkworm leads to all plant extract treatments decreasing the fifth and total larval durations, compared with the blank and control treatments. Both blank and control treatments recorded the highest larval mortality during young and grown instars regardless of insignificant differences in the growth rate during the fourth instar. The growth index during the fourth and fifth instars is almost higher than the control treatment also; the crop of cocoons acquired the highest averages. The same results were noticed for cocooning rate, pupation ratio, cocoon number per liter, cocoon weight, cocoon shell weight, pupa weight, cocoon shell rate, and productivity of silk. Using plant extracts improved most mulberry silkworm characteristics except for the double cocooning percentage. In general, the highest C<sub>3</sub> and C<sub>4</sub> concentrations earned better results for all traits under this investigation so; the application this study of selected plant extracts not only improves silkworm growth but also leads to higher silk production, making it a sustainable strategy to increase profitability in sericulture.

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## Author contributions

T. F. made the experimental design and analyzed statistical analysis for the collected data. Incubating a silkworm egg, dividing the eggs based on the experimental design, preparing the chosen plant extracts, writing the main manuscript text, reviewing the manuscript, and gathering the review were all done. G. A. carried out the practical experiment. gathered the data and reviewed the manuscript. All authors read and approved the final manuscript."

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## Availability of data and material

No datasets were generated or analysed during the current study.

## Declarations

### Competing interests

The authors declare no competing interests.

### Ethics approval and consent to participate

Not applicable.

### Consent for publication

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