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Efficacy of hydrogels under sensor based irrigation in tree mulberry on silkworm growth and cocoon productivity

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Abstract
The silkworm growth and cocoon productivity during 2022-23 were assessed from a well-established V1 tree mulberry garden raised with the hydrogels under sensor-based irrigation. The experiment was laid out in Randomized Complete Block Design (RCBD) with nine treatment combinations and three replications. The hydrogels were applied during beginning of first crop. Main plot includes two different types of hydrogels *viz.,* Pusa hydrogel (T_1- Pusa hydrogel @ 1 kg/ac, T_2- Pusa hydrogel @ 2 kg/ac, T_3- Pusa hydrogel @ 3 kg/ac and T_4- Pusa hydrogel @ 4 kg/ac) and Zeba hydrogel (T_5- Zeba hydrogel @ 3 kg/ac, T_6- Zeba hydrogel @ 4 kg/ac, T_7- Zeba hydrogel @ 5 kg/ac, and T_8- Zeba hydrogel @ 6 kg/ac) and T_9 - control without hydrogel. Tree mulberry grown with the application of Zeba hydrogel @ 6 kg/ac significantly enhanced the Effective Rate of Rearing (ERR) (95.68 per cent), maximum larval weight (46.50 g/ 10 worms), shorter V^{th} instar larval duration (7.16 days) and cocoon parameters *viz.,* single cocoon weight (2.47 g), pupal weight(1.93 g), cocoon shell weight (0.53 g), cocoon shell ratio (23.02 per cent), single cocoon filament length (1368.67 m), non-breakable filament length (1187 m), filament weight (0.45 g), denier (2.95) and silk productivity (7.42). Hydrogels have the ability to retain moisture which can keep the mulberry leaves fresh for longer period and also lead to better silkworm metabolism which inturn enhances the cocoon and reeling parameters. Increased leaf consumption by silkworms due to their enhanced texture and palatability, resulting in improved nutrient uptake and cocoon formation.

Keywords: V_1 tree mulberry, sensor based irrigation, hydrogels and cocoon parameters

Introduction

Silk, a highly valued agricultural commodity which accounts for about 0.20 per cent of the total World production of textile fibers. Silk is the cultural heritage of India. Sericulture is an agro-based industry, wherein the money flows from rich to poor. India is the second largest producer of raw silk and has the distinction of being the World's largest consumer of pure silk. Presently, India produces 25,818 MT of raw silk against its annual requirement of 34, 903 MT of which 7,941 MT is bivoltine silk and 17,877 MT is multivoltine silk. The total cultivation area of mulberry in the country is around 2,08,947 ha. The largest silk-producing state in India is Karnataka, where 1,34,661 farmers practice sericulture and generate 61,419 MT of cocoons from 1,66,000 ha of mulberry gardens, of which 590 ha are planted with mulberry trees (Anonymous, 2022) [1].

The gap between the supply and demand for water is widening annually, and in the near future, its availability will pose a serious threat to the entire world. In a recent report (2009), the Water Resources Consortium observed that, globally, current withdrawals of approximately 4500 km3 exceed availability of approximately 4200 km3. By 2030, demand is expected to rise to 6900 km3, with a slight decrease in availability to 4100 km3, resulting in a 40% deficit. In India, annual demand is expected to rise to nearly 1500 km3, compared with projected availability of 744 km3, resulting in a 50% deficit of water (Narasimhan, 2010) [9].

Though India has the largest irrigation area, the irrigation efficiency has not been achieved more than 40 per cent. Per capita water availability in the country was dropped from 6008 m^3 in 1947 to 1486 m^3 in 2021 and is expected to dwindle down to 760 m3 by 2060 (Johnson and Veltkamp, 1985) [6].

Irrigation water has the greatest effect on mulberry leaf quantity and quality of all the agronomical inputs. Adopting novel irrigation techniques, such as subsurface drip irrigation, which delivers water and nutrients straight to the crop root zone so crops may utilize water and nutrients efficiently, may be necessary to improve the quality and quantity of crop. The need is to maximize the production per unit of water.

Hydrogels are also called as hydrophilic gels or super absorbent polymers are categorised into different groups, such as naturally occurring, semi-synthetic or synthetic. Most of these polymers can retain 332-465 times water to its weight and release it slowly during drought under light soil (Dehkordi, 2016) [4]. Hydrogels are subjected to swelling due to its hydrophilic nature on coming in contact with water and release nearly 95 per cent of stored water available for crop absorption. The process of retaining water and releasing the same by super absorbent gels may last for two to five years depending on the soil environment and cultivation process. However, ultimately in due course of time, it breaks down into CO_2, water, ammonia and potassium ions without any residue, thus making it environment friendly (Trenkel, 1997) [19]. Hydrogels also act as soil ameliorant or conditioner by improving porosity, bulk density, soil permeability, compaction, infiltration rate, *etc.*

Mulberry is the sole food crop for the silkworm (*Bombyx mori* L.). Mulberry is a perennial crop which can be maintained for many years. Selection of land, and adopting recommended package of practices and water management are the imperial factors for producing quality leaves. Among these, irrigation water plays a significant role as one of the key inputs in mulberry cultivation. A medium that is required for the transfer of nutrients throughout the plant is water in the soil plant system. It serves as a temperature regulator, a solvent for biological reactions, a solute distribution medium, and a source of hydrogen for photosynthesis. Under such situation, use of hydrogels to enhance water use efficiency for better productivity of mulberry and cocoon crops can prove as suitable option for the sericulture farmers.

Mulberry leaves' moisture content enhances silkworm nutrition absorption, digestion, and conversion. One of the factors taken into consideration while evaluating the quality of mulberry leaves is their water content. Enhancement of leaf quality and productivity is crucial for the long-term viability of cocoon crops (Seenappa and Devakumar, 2015) [14].

Material and Methods

The experiment was conducted during 2022-23 in well-established V1 tree mulberry garden at L- Block, AICRP- Agro-forestry, University of Agricultural Sciences, Gandhi Krishi Vignana Kendra, Bengaluru. The field is located at a latitude of 12°58′ N, and longitude of 77°35′ East and at an altitude of 930 m above mean sea level in the Eastern Dry Zone (Zone-5) of Karnataka.

The rearing was conducted by using the different treatment leaves in the Department of Sericulture, UAS, GKVK, Bengaluru. The Experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications and nine treatments, comprising of different proportions of hydrogels. Prior to commencement of rearing, the rearing room with rearing stands were cleaned, washed thoroughly and properly disinfected with two per cent formalin solution using a foot pump as adopted by Dandin and Giridhar (2014) [3]. After spraying, the room was kept closed for 48 hours for effective disinfection. After 24 hours of disinfection, the doors and windows were kept open to allow the fresh air into the rearing room. The bivoltine double hybrid (FC1×FC2), third instar silkworms procured from Registered chawki rearing centre, Devanahalli taluk, Bengaluru. The observations from five crops were recorded during 2022-2023. The worms were fed three thrice a day with hydrogels treated V1 variety of mulberry leaves at 6.00 AM, 1.00 PM and 8.00 PM. After the fourth moult the rearing stands were labelled and samples were drawn randomly from different places and the silkworm parameters like fifth instar larval weight, fifth instar larval duration, cocoon weight, cocoon shell weight, pupal weight, cocoon shell ratio, average filament length, non-breakable filament length, filament weight, denier and silk productivity were recorded.

Treatment Combinations

Pusa hydrogel is an indigenous cellulose based product designed and developed to enhance the crop productivity in moisture stress conditions whereas, Zeba hydrogel is an unique starch based soil amendment that absorbs water and releases it back to plants when they need it. The dosage of Pusa hydrogel is 1-2.5 kg/ac and Zeba hydrogel is 5kg/ac.

T_1- Pusa hydrogel @ 1 kg/ac
T_2- Pusa hydrogel @ 2 kg/ac
T_3- Pusa hydrogel @ 3 kg/ac
T_4- Pusa hydrogel @ 4 kg/ac
T_5- Zeba hydrogel @ 3 kg/ac
T_6- Zeba hydrogel @ 4 kg/ac
T_7- Zeba hydrogel @ 5 kg/ac
T_8- Zeba hydrogel @ 6 kg/ac
T_9- Control (Without hydrogel)

Silkworm growth and cocoon parameters of FC1×FC2 hybrid recorded

Ten silkworms and ten cocoons were randomly selected in each treatment for recording observations on growth and cocoon parameters such as V^{th} instar larval weight on V^{th} day (g /10 larvae), V^{th} instar larval duration (hrs), Effective Rate of Rearing (%), single cocoon weight (g), single pupal weight (g), single cocoon shell weight (g), cocoon shell ratio (%), cocoon filament length (m), non-breakable filament length (NBFL) (m), denier and silk productivity.

Fifth instar larval weight (g /10 larvae): Weight of ten grown up silkworms was recorded by randomly picking silkworms from each replication of respective treatments on fifth day of fifth instar.

Fifth instar duration (days): Total number of days taken from the first day of V instar till the time when 50 per cent of the worms ripened was recorded in all the replications and the mean duration was worked out.

Effective Rate of Rearing (%): The number of cocoons harvested at the end of the rearing was recorded and the ERR was calculated by using the formula.

$$\text{ERR (\%)} = \frac{\text{Number of cocoons harvested}}{\text{Total number of worms}} \text{ X } 100$$

Cocoon weight (g): After the cocoon harvest, cocoons were randomly selected from each treatment with respective replications and the mean cocoon weight was calculated.

Pupal weight (g): After obtaining the cocoon weight, same cocoons were cut open and the mean pupal weight was calculated.

Cocoon shell weight (g): Cocoon shell weight of cocoon was noted by removing the pupa and last larval skin. The cocoon shell weight was recorded from the cocoon which was utilized for recording cocoon and pupal weights. At the end, the mean cocoon shell weight was calculated.

Cocoon shell ratio (%): Cocoon shell ratio indicates the total quantity of silk available from the single cocoon and is expressed as a percentage. It was calculated by using the following formula.

$$\text{Cocoon shell ratio (\%)} = \frac{\text{Weight of the cocoon shell}}{\text{Weight of whole cocoon}} \text{ X } 100$$

Average cocoon filament length (m): It is the total length of silk filament, unwound from single cocoon and measured in meters. A sample of five cocoons per replication was randomly drawn and stifled in hot air oven at 70^0C for three hours. The cocoons were cooked in boiling water for three minutes to soften the sericin layer. These cooked cocoons were reeled on an epprouvette with a wheel circumference of 1.125 m. The length of the silk filament was determined by the number of revolutions recorded and converted into meters by the formula:

$TF = R \times 1.125$ m

Where, in
TF = Total filament length (m)
R = Number of revolution

Non-breakable filament length (NBFL) (m): It is the average length of the filament that can be unwound from the cocoon without break.

$$\text{Non breakable filament length(m)} = \frac{\text{Total filament length}}{1 + \text{Number of breaks in filament}}$$

Denier: The raw silk filament was removed from the Eprouvette and weighed after conditioning at room temperature for 24 hrs to determine the denier using the standard formula.

$$\text{Denier} = \frac{\text{Weight of single cocoon filament (g)}}{\text{Single cocoon filament (m)}} \times 9000$$

Where, 9000 = constant value

Silk productivity (cg/day): The silk productivity was calculated replication wise by using the following formula and expressed in cg/day.

$$\text{Silk productivity} \left(\frac{\text{cg}}{\text{day}}\right) = \frac{\text{Weight of cocoon shell(g)}}{\text{Fith instar duration (days)}} \times 100$$

The data recorded on various parameters were subjected to Fisher's method of Analysis of Variance (ANOVA) and interpreted according to Gomez and Gomez (1984) [5]. The level of significance used in F and t-tests was P=0.05 for CRD. The critical difference (CD) values were computed where the F test was found significant.

Results and Discussion

Silkworms fed with mulberry leaves from the V1 mulberry variety raised on Zeba hydrogel @ 6 kg/ac showed positive influence on late age silkworms. However, the different parameters *viz.*, fifth instar larval weight, fifth instar larval duration, effective rate of rearing, cocoon parameters and reeling parameters showed significant difference among the treatments.

Influence of hydrogels under sensor-based irrigation on moisture content and moisture retention capacity after 6hrs. of tree mulberry

Moisture content and moisture retention capacity after 6 hrs. of mulberry leaves varied among different treatment combinations (Table 1). The leaves from the Zeba hydrogel plot @ 6 kg/ac recorded maximum moisture percentage (75.69%) and maximum moisture retention capacity after 6 hrs (83.11%) and that were statistically on par with Zeba hydrogel @ 5 kg/ac. The minimum moisture percentage (70.24%) and minimum moisture retention capacity after 6 hrs (74.27%) were observed when silkworms were fed with mulberry leaves from control plot.

The increase in moisture content in the leaf may be attributed to the enhancement in hydrogen ion concentration of plant sap due to the accumulation of chloride and less moisture loss by evapotranspiration which increasingly supply the moisture and there by increased the moisture in the leaf and fresh leaf weight. Arunadevi and Selvaraj (2007) [2] revealed that the drip fertigation exerted favorable influence on quality parameters. Maximum leaf moisture content (60.09%) and tender leaf moisture content (72.76%) were noticed in mulberry leaves harvested from drip fertigated plots.

When compared to furrow irrigated plots, drip and chapin tape irrigation produced the highest leaf moisture content, according to Siddalingaswamy *et al.* (2007) [17]. This is because of daily irrigation. Comparing the 0.9 CPE level of irrigation to other lower irrigation levels, the leaf moisture content was rather high. According to this, the ideal amount of irrigation needed determines the leaf moisture content.

Table 1: Influence of hydrogels under sensor-based irrigation on moisture content and moisture retention capacity after 6hrs. of tree mulberry

Treatments	Moisture content	Moisture retention capacity after 6 hrs.
T_1	70.68	75.40
T_2	71.44	77.89
T_3	71.89	78.55
T_4	73.31	80.14
T_5	72.54	79.08
T_6	73.92	80.85
T_7	74.10	82.49
T_8	75.69	83.11
T_9	70.24	74.27
F- test	NS	*
S.Em±	-	2.027
C.D.	-	4.147
C.V(%)	-	4.638

Effect of hydrogels on rearing performance of late age silkworm (FC1 × FC2): Influence of hydrogels to mulberry significantly increased rearing performance of late age silkworm (FC1 × FC2) (Table 2). Significant maximum fifth instar larval weight (46.50 g/10 larvae), ERR (95.68%) and shorter fifth instar larval duration (7.16 days) were recorded when silkworms were fed with mulberry leaves from the Zeba hydrogel @ 6 kg/ac plot and that were statistically on par with Zeba hydrogel

@ 5 kg/ac. The minimum larval weight (33.15 g/10 larvae), longer fifth instar larval duration (8.77 days) and lowest ERR (88.44%) were observed when silkworms were fed with mulberry leaves from control plot. Increase in larval weight is apparently due to superior leaf quality. Growth, food absorption, and conversion efficiency in silkworms are all directly impacted by feeding them leaves with a higher moisture content when they are in their fifth instar. Significantly increased meal intake, absorption, and conversion efficiency were observed in batches given tender leaves with a moisture content of 80% to 85%. Silkworms grown faster and reached the growth phase faster in batches fed with tender leaves. Therefore, irrigating the soil more frequently and adding more moisture to it will help sericulturists enhance the moisture content of mulberry leaves (Rahmathulla *et al.*, 2004) [12].

Seenappa and Devakumar (2015) [14] reported that maximum larval weight was recorded with silkworms fed on leaves grown in surface drip irrigation @ 0.75 CPE (29.48 g/10 larvae) while, lowest larval weight was recorded with silkworms fed on leaves grown in micro spray jet (27.10 g/10 larvae).

Shorter larval duration may be due to the balanced nutritional status of the leaves which enable the silkworms to mature early due to the faster metabolic activity. Similar results were observed by Seenappa and Devakumar (2015) [14] reported that shorter fifth instar larval duration was recorded when silkworms were fed on leaves grown in surface drip (7.57 days) than micro spray jet (7.58 days).

Mulberry growth and yield were significantly increased after application of NPK @ 400:180:25 kg-1 ha-1 yr-1, as were larval duration, larval weight and reduced moulting duration. The cocoons that were spun were of good quality (Sreerama, 2006) [18].

Rajaram and Qadri (2014) [13] reported maximum cocoon yield of 19.80 kg obtained from 10,000 larvae reared under treatment combinations of V-1 variety with drip irrigation at 50 per cent followed by sprinkler irrigation at 70 per cent CPE and furrow irrigation at 100 per cent CPE. At lower levels of irrigation on yield performance among treatments in respect of variety, methods and levels of irrigation all three factors combined together did not showed any significant difference.

Table 2: Effect of V1 mulberry leaves on silkworm (FC1×FC2) as influenced by hydrogels under sensor based irrigation

Treatments	V^{th} instar larval weight (g/10 larvae)	Effective Rate of Rearing (%)	V^{th} instar larval duration (h)	Cocoon yield by number (per 10000 larvae)
T_1	34.29	89.68	8.68	8999.99
T_2	36.09	90.20	8.50	9165.71
T_3	38.13	91.79	8.32	9242.33
T_4	40.11	93.14	8.11	9389.12
T_5	40.32	92.91	8.27	9285.11
T_6	43.04	93.48	8.00	9448.06
T_7	45.39	94.21	7.77	9490.35
T_8	46.50	95.68	7.16	9573.12
T_9	33.15	88.44	8.77	8912.94
F- test	*	*	*	NS
S.Em±	0.792	0.893	0.299	-
C.D.	2.281	2.571	0.862	-
C.V(%)	4.465	2.165	8.187	-

Effect of hydrogels on cocoon parameters of silkworm (FC1 × FC2): The silkworms fed with mulberry leaves from Zeba hydrogel @ 6 kg/ac plot recorded maximum single cocoon weight (2.47 g), single pupal weight (1.93 g), cocoon shell weight (0.50 g), cocoon shell ratio (23.02%) and cocoon yield per 10,000 larvae (25.00 kg) (Table 3). The lowest single cocoon weight (2.03 g), pupal weight (1.61 g), shell weight (0.42 g), cocoon shell ratio (20.48%) and the cocoon yield (20.95 kg) were observed when silkworms were fed with mulberry leaves from control plot.

The present results are in close conformity with the earlier studies of Naveen *et al.* (2019) [10] who reported that the performance of silkworm, *Bombyx mori* L. in terms of cocoon weight (g/10 cocoons), cocoon shell weight (g/10 cocoons) and cocoon shell ratio (%) were higher in the treatment receiving 75 per cent water soluble NPK fertilizes + FYM.

Similar results were observed during study conducted by Seenappa and Devakumar (2015) [14] who reported maximum single cocoon weight (1.63 g), highest shell weight (0.30 g), shell ratio (18.11%), and cocoon yield (59.63 kg/100 DFLs) when worms fed with leaves grown under surface drip irrigation than micro spray jet irrigated plot (1.53 g, 0.27 g, 16.25% and 55.17 kg/100DFLs). Maximum pupal weight was registered when silkworms fed on leaves grown in surface drip irrigation (1.33 g) than silkworms fed on leaves of micro spray jet (1.25 g).

The current study is in line with the results of Rajegowda *et al.* (2020) [11] who reported that maximum pupal weight of 1.33 g/pupa was recorded in cowpea intercropped tree mulberry over sole tree mulberry (1.23 g/pupa).

In line with the present observations, Shankar *et al.* (2000) [16] also reported that feeding of mulberry leaves with higher concentration of nutrients recorded significantly higher pupal weight compared to control. Therefore, the leaf quality largely determines the performance of silkworms during their development and spinning of cocoons.

Table 3: Effect of V1 mulberry leaves on cocoon parameters of FC1×FC2 as influenced by hydrogels under sensor based irrigation

Treatments	Cocoon weight (g)	Pupal weight (g)	Single shell weight (g)	Cocoon shell ratio (%)	Cocoon yield by weight (kg per 10000 larvae)
T_1	2.07	1.65	0.42	20.65	21.39
T_2	2.19	1.73	0.46	20.87	21.89
T_3	2.29	1.82	0.46	21.09	22.70
T_4	2.34	1.86	0.47	21.41	23.58
T_5	2.30	1.83	0.47	21.30	23.17
T_6	2.38	1.89	0.49	22.14	23.49
T_7	2.41	1.90	0.50	22.30	24.74
T_8	2.47	1.93	0.53	23.02	25.00
T_9	2.03	1.61	0.42	20.48	20.95
F- test	*	*	*	*	**NS**
S.Em±	0.078	0.039	0.020	0.515	-
C.D.	0.224	0.111	0.058	1.483	-
C.V(%)	7.633	4.789	9.667	5.363	-

Effect of hydrogels on cocoon reeling parameters of silkworm hybrid (FC1 × FC2): The average filament length (1368.67 m), non-breakable filament length (1187.53 m), filament weight (0.45 g), denier (2.95) and silk productivity (7.42 cg/day) were significantly higher when silkworms fed with V1 mulberry leaves from Zeba hydrogel @ 6 kg/ac plot. However, comparatively shorter average filament length (1220.73 m), non-breakable filament length (1036.77 m) and minimum filament weight (0.34 g) were recorded when silkworms were fed with mulberry leaves from control plot. The lower denier (2.50) and silk productivity (4.76 cg/day) was recorded when silkworms were fed with mulberry leaves from control plot (Table 4). This might be due to irrigation with hydrogels resulted in enriched nutrition in mulberry leaves which have in turn influenced better growth of silkworms, yielding higher proportions of silk proteins and spinning of long silk thread. These results only signify the close relationship between higher nutrient status of the leaf and silkworm nutrition which resulted in higher cocoon parameters.

Seenappa (2015) [15] reported that when silkworms fed on leaves grown with surface drip irrigation recorded higher single cocoon filament length (757.65 m) and highest denier (2.49) in crossbreed cocoons while, the lowest was observed when silkworms fed on leaves grown with microspray jet irrigation.

Maribashetty *et al*. (1999) [8] studied the impact of mulberry leaves from bush and tree system of plantations on silkworm performances at different seed multiplication levels. The results showed that the pupation rate of batches fed with tree mulberry leaves was higher at all multiplication levels. In addition, moth emergence and number of laying per kg of cocoons were significantly higher (P >0.5) in batches fed with tree mulberry leaves.

The results are also in conformity with Kumar *et al*. (2015) [7] who reported that the maximum cocoon shell weight (3.51 g/10 shells) was observed in mulberry and soybean intercropping over control (2.59 g/10 shells).

Table 4: Silk filament characteristics of FC1×FC2 as influenced by hydrogels under sensor based irrigation to V1 mulberry

Treatments	Average Filament length (m)	Non-breakable filament length (m)	Filament weight (g)	Denier	Silk productivity (cg/day)
T_1	1246.87	1062.92	0.36	2.59	4.81
T_2	1257.63	1084.11	0.38	2.71	5.40
T_3	1260.53	1095.49	0.38	2.78	5.52
T_4	1274.50	1107.64	0.41	2.89	5.79
T_5	1268.33	1098.46	0.39	2.83	5.67
T_6	1289.60	1111.19	0.41	2.86	6.12
T_7	1305.10	1142.67	0.41	2.89	6.43
T_8	1368.67	1187.52	0.45	2.95	7.42
T_9	1220.73	1036.77	0.34	2.50	4.76
F- test	**NS**	*	*	*	*
S.Em±	-	28.47	0.013	0.038	0.254
C.D.	-	82.01	0.039	0.110	0.732
C.V(%)	-	5.773	7.593	3.071	9.850

Conclusion

The Zeba hydrogel under sensor-based irrigation had positive influence on silkworm FC1 x FC2 when fed with mulberry leaves. The mulberry leaves harvested from hydrogel applied plot remain fresh for the longer period of time, promoting consumption and conversion efficiency of food in silkworms, thus resulting in better performance in terms of growth, development and productivity.

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