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Productive and qualitative characteristics of sericulture in Brazil in Domestic and Non-Domestic rearing systems

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PALAVRASCHAVEADICIONAIS
Bombyx mori.
Cadeia da seda.
Casulos.
Pupas.
Sustentabilidade.

RESUMO

Objetivou-se avaliar a produção e qualidade de lagartas, pupas e casulos de bicho-da-seda em diferentes sistemas de criação no Brasil. Foram utilizadas 240 lagartas híbridas de Bombyx mori L. no terceiro instar, divididas em dois tipos de sistemas, o Doméstico e Não Doméstico, totalizando 120 animais por sistema. No Doméstico eram criadas em caixas de papel e manejo não tecnificado. Enquanto, no Não Doméstico eram criadas em barracão de criação sericícola, manejo assistenciados e tecnificados. Para realização de análises foram coletas de ambos os sistemas de criação, 40 lagartas no último dia do quinto ínstar e 60 casulos no terceiro dia após o início da construção dos mesmos. Foi observado melhor produção e qualidade para as medidas observadas nas lagartas (peso da lagarta e peso da glândula sericígena), nos casulos (peso do casulo, peso da casca sérica, largura e comprimento do casulo) e nas pupas (peso de pupas) para os bichos-da-seda criados no sistema Não Doméstico. Nenhuma diferença foi observada para casulos desclassificados, teor de seda liquida e pupas mortas. Entretanto, estes parâmetros impactam diretamente sobre o lucro do sericicultor. Com base nos resultados obtidos, recomenda-se apostar na criação do bicho-da-seda no sistema Não Doméstico, onde se obtém casulos de melhor qualidade e com maior teor de seda líquida.

Características produtivas e qualitativas da sericultura no Brasil em sistemas de criação doméstico e não doméstico

SUMMARY

The objective of this study was to evaluate the production and quality of silkworm larvae, pupae and silkworm cocoons in different rearing systems in Brazil. 240 Bombyx mori L. hybrid silkworms were used in the third instar, divided into two types of systems, Domestic and Non-Domestic, totaling 120 animals per system. In the Domestic, rearing was taken in cardboard boxes and non-technical handling. While, in the Non-Domestic system, they were reared in a sericultural farming shed, assisted and technically managed. For analysis, samples were collected from both rearing systems, 40 larvae on the last day of the fifth instar and 60 cocoons on the third day after they started to be built. Better production and quality was observed for the measures observed in silkworms (larvae weight and sericigenic gland weight), cocoons (cocoon weight, cocoon shell weight, cocoon width and length) and pupae (pupae weight) for silkworms reared in the Non-Domestic system. No difference was observed for declassified cocoons, liquid silk content and dead pupae. However, these parameters have a direct impact on the profit of the silkworm farmers. Based on the results obtained, it is recommended to bet on a silkworm rearing under the Non-Domestic system, where better quality cocoons are obtained with a higher liquid silk content.

ADDITIONAL KEYWORDS
Bombyx mori.
Cocoons.
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INTRODUCTION

Sericulture can be considered as a rational and sustainable use of the silkworm in order to produce silk and other by-products in the chain. It is an agro-industrial activity that contributes to the economy of several countries (INSERCO n/d), impacting on a gradual annual increase in world silk production. China with 80% of the market is the largest world producer, followed by India, with 18% and Brazil occupies the fifth place with 0.34% of world production (State Secretariat for Agriculture and Supply [SEAB] 2018). In Brazil, the State of Paraná is the largest producer, with 2.46 tons per year, corresponding to 83% of national production, followed by São Paulo State.

Currently, Bratac Inc. is the only silk production and spinning company in Brazil. It carries out everything from obtaining the silkworm eggs, delivering third instar silkworms to farmers up to selling silk (Cirio 2018). This Company provides technical support to producers in all stages: the construction of the sheds, mulberry tree implantation and daily handling in the silkworm rear. According to Porto (2019), it is an activity performed entirely as a vertical integrated agricultural system. The relationship is established by a contract of the union of goods and labor between the silkworm farmer and the Company, where the products obtained are sold by the producer directly to the industry. It is interesting to note that the Company defines the price of the kilo of cocoons paid to the Brazilian silkworm farmer, according to the percentage of silk content. In this case, may increase up to 20% in the price paid per kilo of cocoons with 18% of raw silk in relation to those with 15%. Still, cocoons considered second-class, of lower quality, are worth 460% less than those of first quality (18% of raw silk).

The silk thread produced in Brazil, considered the highest quality by the international market (Sabbag, Nicodemo & Oliveira 2013), is obtained by a non-domestic silkworm rearing system. This system requires specific sericultural sheds, with an appropriated production technology. Normally involves the farmer's family in the activity and it is estimated that on average the farmer rears simultaneously three boxes of silkworms (35,000 larvae/box). However, this is not the reality of important silk producing countries in the world. Countries such as India, China and Thailand have relevant domestic production of cocoons, which characterizes a more artisanal production, with lack of appropriated technology and a low production per silkworm production unit. Patil et al. (2009), report that among the sericulture farmers who participate in support programs in India, 80% of the families are inserted in rural areas, are poor and make domestic sericulture a way of obtaining income.

Silkworm rearing is part of a sustainable system that seeks to respect the environmental, social and economic pillars. The larvae must not have contact with pesticides, which creates a prohibition on their use in the mulberry field and allows leftover pruning to return to the crop, contributing to the environment. Sericulture in Brazil is performed mostly by small farmers and employs family labor and practically all the by-products and waste produced is used. Silkworm feces can be used for fertilization of mulberry trees, such as the production of pupae that can contribute to human and/or animal food, as an interesting protein and energy source (Akande et al. 2020; Novodworski, Guedin & Silva 2020). According to Buhroo et al. (2018) many countries discard pupae after processing silk threads obtained from cocoons.

For the silkworm farmer to obtain a good production and, consequently, profitability with silkworm rearing, it is necessary to obtain healthy larvae and pupae, in order to achieve cocoons of good final quality. The knowledge of these characteristics in the different rearing systems will be able to increase the world silk production, in productive units of bigger or smaller scale. Therefore, the objective of this work was to evaluate the production and quality of silkworms, pupae and silkworm cocoons in two different rearing systems, Domestic and Non-Domestic.

MATERIAL AND METHODS

They were used 240 hybrid silkworm of *Bombyx mori* L., in their third instar, from the same rearing flock and supplied by Fiação de Seda Bratac Inc. (located in the State of Paraná, Brazil), which were randomly distributed into the two treatments (Domestic and Non-Domestic systems), totaling 120 larvae in each treatment. The experiment was carried out between the months of October and November 2019, so that, in the feeding of both treatments, mulberry branches (*Morus spp.*) of the same variety "Miura" were used and with the same frequency of daily feeding (3 times a day) until the spinning of cocoons period. Likewise, in both treatments (Domestic and Non-Domestic system) were reared under controlled temperature and average humidity (25ºC (± 2) and 70% (± 10%)). However, both rearing systems respected the density of 1200 silkworms/ m².

In the Domestic system, the silkworms were kept in disposable cardboard boxes (70 cm x 60 cm x 10 cm) properly lined with paper and with an opening for gas exchange and environmental control, and in the daily care, inexperienced labor was employed for the activity. Mulberry branches were collected every three days and kept under refrigeration to avoid wilting and decreased nutritional quality. The boxes were cleaned daily and eventually the dead larvae were removed. During the spinning cocoon period, a replica of the japanese rotary mountage was made, which was handcrafted using discard cardboard, with an available spacing of 4.5 cm x 3.0 cm x 3.0 cm per silkworm.

In the Non-Domestic system, the silkworms were reared in a sericultural shed with rearing beds made of bricks and control of humidity and temperature by opening and closing the curtains. The management was carried out by family labour with experience in the activity and in accordance with the technical guidelines of Bratac Inc., used by all sericulture farmers in Brazil. The offered mulberry branches were collected in the mulberry field next to the shed, always at the beginning of each morning by the farmers and stored in an appropriate place to be available for the daily feeding times. During the spinning cocoon period, the silkworms had access to the japanese rotary mountages, with available space of 4.5 cm x 3.0 cm x 3.0 cm per silkworm. The japanese frames were suspended over the silkworm beds, going down and up by an automatic system with motor and belts to allow silkworms climb on them and spin the cocoons.

For laboratory analysis, were collected 40 larvae, on the last day of the fifth instar and 60 cocoons, on the third day after the beginning of their construction, from both rearing systems according to the variables described below.

The percentage of Dead Pupae (DP) was obtained after counting dead pupae during the rearing period and calculated according to the number of total cocoons. Silkworm Weight (SW) was obtained at the end of the larval period and measured with precision analytical balance, being expressed in grams. Weight of the Sericigenic Gland (SGW) was assessed on the eighth day of the fifth instar, before the start of spinning cocoon period. The selected silkworms were anesthetized at -20ºC and dissected through the longitudinal opening of the integument, from the anal region to the height of the head, under a binocular stereoscopic microscope Optika ST-40-2L. The tissues of the sericigenic gland were weighed in individualized identified capsules, determining the unit weight of each gland in grams, using a precision analytical balance, as described by Porto et al. (2004). Declassified Cocoons (DC), obtained by observation, counting, separation and subsequent transformation into a percentage of the number of cocoons considered as non-reelable cocoons, according to Tinoco (2000). Cocoon Weight (CW), corresponds to the cocoon weight measured with precision analytical balance, values being expressed in grams. Cocoon Shell Weight (CSW), refers to the weight of the cocoon without the pupae, determined with precision analytical balance and expressed in grams. Cocoon Length (CL) and Cocoon Width (CCW), each cocoon was evaluated using a 0-200 mm digital caliper with 0.01mm precision and ruler, the values being expressed in millimeters. Percentage of Liquid Silk Content (SLC), for the calculation of liquid silk content, the formula (CSW - CW) x 100 - 24% (unreliable portion) was applied, according to Oliveira et al. (2010). Pupae Weight (PW), the average unit weight measured with electronic balance ES-500, the values were expressed in grams.

Statistical analysis was performed using software R version 3.6.0 and the spreadsheet editor Microsoft Office Excel 2010. The variables considered in this study were: SW - Weight of the Silkworm (mg), SGW - Weight of the Sericigenic Gland (mg), CW - Cocoon Weight (mg), CSW - Cocoon Shell Weight (mg), PW - Pupae Weight (mg), CCW - Cocoon Width (mm), CL - Cocoon Length (mm), DC - Declassified Cocoons (%), SLC - Liquid Silk Content (%) and Dead Pupae (%), among the experimental groups Domestic and Non-Domestic rearing systems. Univariate descriptive analysis was used to extract initial information from the data. As for the assumption of normality of the variables, for both experimental groups, the Shapiro-Wilk test was used. Once the normality hypothesis was satisfied, the t-Student test was used to find out whether, on average, there are significant differences in the measurements of the variables already listed between the experimental groups. In cases where the hypothesis of normality was violated, the Mann-Whitney-Wilcoxon U test was used. For the variables that were considered in the proportion scale, Fisher's Exact Probability test was used. In all tests, the adopted level of significance was 5%.

RESULTS

Mean obtained for the variables Silkworm Weight (SW), Weight of the Sericigenic Gland (SGW), Cocoon Weight (CW), Cocoon Shell Weight (CSW), Pupae Weight (PW), Cocoon Width (CCW) and Length of the Cocoon (CL) for the experimental groups Domestic and Non-Domestic rearing systems are shown in **Table I**.

The results show that the variables related to silkworms (SW, SGW), cocoons (CW, CSW, CL and CCW) and pupae (PW) were higher for insects submitted to the Non-Domestic system in comparison to those produced in the Domestic system.

Table II shows the percentages obtained for Declassified Cocoons (DC), Liquid Silk Content (SLC), Dead Pupae (DP) for the experimental Domestic and Non-Domestic rearing groups. All percentages obtained for these variables were similar between the cocoons and pupae obtained in the Domestic and Non-Domestic rearing systems.

DISCUSSION

Silkworm Weight (SW) is related to several factors such as genetic, the physiological stage of development, feeding and the environmental condition of rearing. Increased weight for silkworms reared in the Non-Domestic system (3.83g) compared to those of Domestic rearing (2.49g) is probably due to the last two factors mentioned previously. According to Samami et al. (2019), the performance of silkworm production plays a key role in the sericulture industry. Still, larger larvae may have more potential in silk production, since the sericigenic glands can represent up to 30% of the silkworm's body weight (Oliveira et al. 2010). Both silkworms of the two rearing systems, presented lower PL than those reported by Porto et al. (2004), 4.7g; Meneguim et al. (2007), from 4.3 to 4.9g and Oliveira et al. (2010), with an average of 4.1g. Such differences are probably due to the difference between the hybrids used and the annual rearing period.

The Weight of the Sericigenic Gland (SGW) was higher for larvae reared in the Non-Domestic system compared to those in the Domestic system, corroborated by the greater weight of silkworms reared in the same system (**Table I**). The silk gland is the most important larvae organ for silk production, being responsible for the synthesis of silk proteins, production, storage and processing of silk fibers (Xia, Li & Feng 2014). In the same vein, Takahashi, Landim, & Kronka (1990) infer that the size of the sericigenic gland has a great impact on the silk production made by the silkworm. The peak of production of sericin and fibroin, the main proteins that make up the silk thread, occurs in the fifth instar of the larval stage. Greater development of the sericigenic glands implies the production of larger cocoons (Miranda, Bortoli & Takahashi 2012).

Both results obtained for SGW were inferior to those reported by previous national studies, in which they researched with silkworms fed with different cultivars of mulberries and different hybrids. Such authors report SGW values from 0.94g to 1.75g (Takahashi, Landim, & Kronka 1990; Porto et al. 2004; Porto et al. 2005; Marchi et al. 2009 and Miranda, Bortoli & Takahashi 2012). Among the possibilities for lower SGW in this work (0.60g for Domestic rearing and 0.88g for Non-Domestic rearing systems) compared to those found in the literature are the same possible causes presented for the lowest SW, added by the fact of the great incidence of pesticide drift that mulberry crops have been affected during the period of this experiment. It is known that contamination with pesticide drift not only affects the performance of the mulberry plantation but also the silkworms, ranging from a decrease in consumption to their death (Kuribayashi 1988).

The Cocoon Weight (CW), similarly to the previous variables, presented lower values for the Domestic rearing system (1.524g) compared to the Non-Domestic system (1.757g). Smaller cocoons can be observed from food restriction of the silkworms, diseases, between different breeds and even from the quality and dimensions of the place where the larvae spin the cocoons, called mountages. Larger cocoons are more appreciated than smaller ones, in addition the good quality cocoon represents the main economic factor in silkworm farms (Samami et al., 2019). Samami et al. (2019) evaluated eight different hybrid silkworms and observed fresh cocoon weights from 1.473g to 1.587g. National previous studies have reported values of 1.36g to 2.33g, silkworms fed on different mulberry cultivars and different hybrids (Porto & Okamoto, 2003; Porto et al., 2005; Meneguim et al., 2007; Oliveira et al. , 2010; Miranda, Bortoli & Takahashi, 2012). Thus, the values obtained for CW in this experience fit the average obtained in other works.

Cocoon Shell (CSW) refers to the portion of the fresh cocoon effectively used in the spinning of the silk thread; the main product obtained from silkworm rearing. According to Nagata & Nagasava (2006), the profit from the sericultural activity is directly related to a good cocoon shell production. Thus, thin-shell cocoons are not desired by farmers as they are less valued as well as by the spinning industry, which declassifies these cocoons and generates products with lower added value. Domestic rearing system produced lighter CSW (0.317g) compared to Non-Domestic system (0.442g), which may be related to its lower quality for SW, SGW and CW. It is suggested a relationship where the larger the silkworm is, the greater the weight of the sericigenic gland, the greater the weight of the cocoon and consequently the cocoon shell. Porto & Okamoto (2003) working with four breeds and their hybrids of *Bombyx mori*, observed an average CSW value of 0.299g, which is a lower weight than the one founded for Domestic system. Other researchers founded higher values for this characteristic, ranging from 0.365g to 0.500g (Porto et al., 2005; Meneguin et al., 2007; Oliveira et al., 2010; Miranda, Bortoli & Takahashi, 2012).

Table I. **Mean obtained for the variables silkworm weight (SW), weight of the sericigene gland (SGW), cocoon weight (CW), cocoon shell weight (CSW), pupae weight (PW), cocoon width (CCW) and length of the cocoon (CL) for the experimental groups Domestic and Non-Domestic rearing systems** (Média obtida para as variáveis peso do bicho-da-seda (SW), peso da glândula sericigene (SGW), peso do casulo (CW), peso da casca do casulo (CSW), peso da pupa (PW), largura do casulo (CCW) e comprimento do casulo (CL) para os grupos experimentais Sistemas de criação domésticos e não domésticos).

Variables	Rearing systems		p - Value
	Domestic	Non-Domestic	
SW (g)	2.49 (0.07)***	3.83 (0.05)	<0.001*
SGW (g)	0.60 (0.02)	0.88 (0.01)	<0.001**
CW (g)	1.524 (0.33)	1.757 (0.05)	0.04*
CSW (g)	0.317 (0.09)	0.442 (0.06)	<0.001*
PW (g)	1.15 (0.26)	1.34 (0.09)	0.04*
CCW (mm)	18.01 (0.14)	19.07 (0.22)	<0.001**
CL (mm)	31.35 (0.23)	32.85 (0.37)	<0.001**

* t-Student Test; ** U Mann – Whitney-Wilcoxon Test; *** Mean followed by standard error

Table I also shows that the Pupae Weight (PW) obtained in the Non-Domestic system (1.34g) was higher than Domestic system (1.15g). Corroborating these results, the CW was also inferior in Domestic rearing system. PW is an important characteristic used in the selection of silkworms for reproduction and genetic improvement. In this case, healthier and heavier and larger pupae are appreciated. Pupae are by-products of the sericulture chain and are discarded by some countries. They are excellent nutritional sources of energy and protein and have shown a great importance in animal (Novodworski, Guedin & Silva, 2020) and human nutrition (Akande et al., 2020), being traditionally consumed in some Asian countries (Buhroo et al., 2018). The PW values founded in this work are higher than those founded by Porto & Okamoto (2003) and are in the ranges between 1.15 and 1.90, observed by Porto et al. (2005) and Meneguin et al. (2007), respectively.

The measures of Width (CCW) and Length (CL) of cocoon are interesting data of productivity, however they may not be directly proportional to the CW, means that large cocoons may have less weight. In this research, for both variables, CCW and CL, we observed that the cocoons obtained in the Non-Domestic system had higher values. Small cocoons, as well as spotted, irregular ones, among others, are considered as second quality in Brazil. The genetics of larvae can be an important factor in the production of small cocoons or as already mentioned, poor handling and/or poor diet can result in these products. Porto and his collaborators (2004) researching some productive characteristics of the silkworm, observed cocoons of eight different hybrids that on average had 29.53mm of CL and 16.75mm of CCW, values that are inferior to those obtained in this work. The authors do not report the CW, but the SGW was 0.943g, higher than our results.

Declassified Cocoons (DC) are those that have internal or external stains, defects due to mountages, thin shell, perforated cocoon or double cocoons, among others. Usually the percentage of DC generates a decrease in the amount to be paid for the cocoons, impacting the silkworm farmer's incomes. There was no difference in DC between the two proposed rearing systems (**Table II**), but a DC of 17% in Domestic rearing system will generate a lower profit for the farmer in relation to the DC obtained in Non-Domestic system of 10%. Better handling conditions in the different stages of rearing

Table II. Relative frequency (%) for declassified cocoons (DC), liquid silk content (SLC), dead pupae (PM), for the experimental Domestic and Non-Domestic systems (n=100) (Frequência relativa (%) para casulos desclassificados (DC), teor de seda líquida (SLC), pupas mortas (PM), para os sistemas domésticos e não domésticos experimentais (n = 100)).

Variables	Rearing systems (%)		p-value
	Domestic	Non-Domestic	
DC	17.00 (1.15)*	10.00 (0.94)	0.21
SLC	15.68 (2.58)	18.70 (2.17)	0.30
DP	17.00 (1.64)	21.00 (1.19)	0.58

p-value considered significant in Fisher's Exact Probability Test ≤ 0.05; *Mean followed by standard error.

and the experience of the silkworm farmer in Non-Domestic system should contribute to a better performance. These results corroborate with the understanding that the production in the Non-Domestic system is more efficient while the Domestic one. Porto (2008) found maximum DC values of 8.27% for silkworms reared under controlled conditions in a laboratory.

The Liquid Silk Content (SLC) is also considered an important parameter of economic income to produce silkworm cocoons (Miranda, Bortoli & Takahashi, 2012). Although we did not find a statistical difference between the contents of liquid silk of larvae of Domestic (15.68%) or Non-Domestic (18.70%) systems, according to the marketing method applied in Brazil, in which farmers are payed according to silk content of their cocoons, the incomes of farmers who produce cocoons in the Domestic system would have a 12.3% less compared to farmers in the Non-Domestic system. In general, the values obtained from SLC are not below those found by other groups. Miranda, Bortoli & Takahashi (2012) found the highest SLC values, 23.32%, followed by Oliveira et al. (2010) with TSL of 16.47%, Porto et al. (2004) of 16.37 and finally Porto et al. (2005) with 15.00%.

Even though the percentage of Dead Pupae (DP) did not differ between those produced in the Non-Domestic rearing system (21%) versus the Domestic one (17%), such rates are considered high and have an impact to the silkworm farmer. It is probable that silkworms have been affected by pesticide drifts, which can lead to pupae death even after the construction of their cocoons. Unfortunately, this situation has caused losses of around 8% of the total Brazilian production in recent years. Not far from the results obtained, a mortality rate of 20.50% was reported by Porto et al. (2004). On the other hand, the same authors obtained, in another study, very interesting mortality rates, of 1.25% (Porto et al., 2005).

CONCLUSIONS

Brazilian sericulture production has its own characteristics that make it different from the silk production of other countries. In this framework, the fact that there is a single company that supplies the larvae to the farmers, buys all the cocoons produced and processes them to obtain the silk thread, is a key factor to take into account when analyzing sericulture in this country.

Although rearing under the Domestic system is feasible, it is only recommended in the case of those people who have just started the activity and who seek to become familiar with it. The cocoons obtained in the Domestic system tend to present a higher level of heterogeneity and lower quality derived from management where environmental conditions are not controlled correctly and where there is a lack of labor with previous experience.

Otherwise, and based on the results obtained, it is recommended to bet on a silkworm rearing under the Non-Domestic system, where better quality cocoons are obtained with a higher liquid silk content. This parameter is of great importance when selling the cocoons, since the company pays a bonus based on the percentage of raw silk obtained. An improvement in the management of the production system translates into an increase in cocoon yield and in their quality, which translates into an increase in the profit perceived by the Brazilian silkworm farmer.

We suggest further investigations that deal with the economic viability between the two rearing systems proposed in this work in more detail. It is important to consider that the goal of the rearing stage is predeterminant for choosing the one that can best respond to the demand of a determinated region and cultural and economic reality.

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