REPRODUCTIVE PERFORMANCE AND SPERM QUALITY IN WILD AND POND-REARED SOUTHERN WHITE SHRIMP *Litopenaeus schmitti* ADULT MALES DURING CONTINUOUS REPRODUCTIVE ACTIVITY

Lourdes Pérez-Jar [1] *, Laida Ramos [2], Elena Palacios [3] e Ilie S. Racotta [3]

(1) Centro de Investigaciones Pesqueras, Ministerio de la Industria Pesquera, 5ta Ave. y 246, Playa, CP 19100, Ciudad Habana,, Cuba
(2) Centro de Investigaciones Marinas, Universidad de La Habana, Calle 16 Nº 114, Playa, CP 11300, Ciudad Habana, Cuba.
(3) Programa de Acuicultura, Centro de Investigaciones Biológicas del Noroeste (CIBNOR), Mar Bermejo 195, Col. Playa Palo de Santa Rita, La Paz, Baja California Sur, CP 23090, México.
(*) Corresponding author: Email: tropical@cip.telemar.cu

ABSTRACT

Pond-reared populations of southern white shrimp (*Litopenaeus schmitti*) are commonly used for nauplii production in Cuba, although their performance compared to wild population has not been evaluated. The present study compares reproductive performance and sperm quality of wild and pond-reared *L. schmitti* males over a production cycle of 70 days. Spermatophore weight was significantly higher for wild shrimp and these differences were not related to body weight or sperm count, suggesting a higher quantity of agglutinating mass. However, sperm quality, percentage of mated females, and number of nauplii per spawn were not different between both populations, whereas fertilization rate was higher for pond-reared shrimp. A decrease in the percentage of normal sperm cells and an increase in dead sperm cells count were observed mainly in wild males, concomitant to a more steep decrease in the fertilization rate and nauplii per spawn towards the end of the production period for this population. An increase in temperature from day 59 and a significant negative correlation between temperature and fertilization was found only for wild males, suggesting a better adaptation of pond-reared males to captive conditions, particularly high temperatures.

Key words: broodstock; temperature; fertilization rate; reproductive exhaustion; shrimp culture; *Litopenaeus schmitti*.

RESUMEN

El camarón blanco *Litopenaeus schmitti* criado en ciclo cerrado era comúnmente usado para la producción de nauplios en Cuba. En el presente estudio fue comparado el desempeño reproductivo y la calidad espermática entre machos de cultivo y silvestres a lo largo de un periodo productivo de 70 días. El peso del espermatóforo significativamente superior en machos silvestres no se correlacionó con el conteo total de espermatozoides. No existieron diferencias teniendo en cuenta el origen de los animales entre los indicadores reproductivos calidad espermática, porcentaje de hembras copuladas, y número de nauplios por desove, mientras que para el porcentaje de fertilización se observaron valores superiores en los animales de cultivo. Una disminución en el porcentaje de células espermáticas normales y un incremento en las células espermáticas muertas, fueron detectadas principalmente en machos silvestres, contribuyendo a un decremento pronunciado en el porcentaje de fertilización y nauplios por desove fundamentalmente al final del periodo productivo de esta población. Para el lote de machos silvestres fue observada una correlación negativa entre la temperatura y el indicador productivo porcentaje de fertilización, lo cual sugiere que los machos de cultivo presentaron una mejor adaptación a las condiciones de cautiverio, particularmente con relación a las altas temperaturas presentes a partir de finales del segundo mes del ciclo de reproducción de los animales.

Palabras claves: reproductores; temperatura; porcentaje de fertilización; agotamiento reproductivo; cultivo de camarones; *Litopenaeus schmitti.*

Southern white shrimp *Litopenaeus schmitti* is important for aquaculture in Cuba, because among the endemic species of this country it presents the highest yields in production. Maturation and spawning of pond reared broodstock has been achieved since 1990 (Ramos *et al.*, 1995) and several studies have been directed to improve the reproductive performance of domesticated stocks (Bécquer *et al.*, 1994; Pérez-Jar y Jaime, 1995; Ramos *et al.*, 1995; Pérez-Jar *et al.*, 1996; 1997). As reported for other penaeid species, the use of pond-reared broodstock can

result in important advantages over wild stock, if reproductive performance and offspring quality are not affected (for review see Browdy, 1998; Racotta *et al.*, 2003).

Comparison of reproductive performance between wild and pond-reared broodstock has been made for several shrimp species with variable results, depending mainly on stocks and shrimp size (for review see Racotta *et al.*, 2003). For *L. schmitti*, there is only one known study that compared reproductive performance of wild vs. pond-reared males mated with pond-reared females, and more spawns and higher hatching rates were obtained using wild males, although no statistical comparison was applied (Ramos *et al.*, 1995). In other species, comparison of reproductive potential between wild and pond-reared shrimp has been done mostly in females (Medina *et al.*, 1996; Palacios *et al.*, 1999a). On the other hand, reproductive performance can also be evaluated using productive variables such as spawning frequency, fecundity, fertilization, hatching, and number of nauplii, where the last three depend on both sexes. In many studies, such evaluation is done using both sexes from different origins separately (Browdy *et al.*, 1986; Menasveta *et al.*, 1993; Cavalli *et al.*, 1997; Palacios *et al.*, 1999b; 2000; Preston *et al.*, 1999; Peixoto *et al.*, 2003). However, separation of sexes by origin does not allow for the evaluation of a particular influence of males on production variables. For this purpose, males from different origins should be mated with females from one origin (Menasveta *et al.*, 1993; Ramos *et al.*, 1995; Mendoza, 1997), or the reproductive potential of wild and pond-reared males in terms of sperm count and quality should be analyzed (Pratoomchat *et al.*, 1993).

It is also well known that reproductive performance and offspring quality decrease with time spent in production (Palacios *et al.*, 1999c; Racotta *et al.*, 2003) and at least for some species, a decrease in sperm quality has been observed over time or consecutive spermatophore regeneration (Leung-Trujillo and Lawrence, 1987; Alfaro and Lozano, 1993; Pascual *et al.*, 1998). For *L. schmitti*, Pérez-Jar (1996) observed that reproductive performance decreased over time in terms of female chasing by males and the fertilization rate, both partially attributed to male reproductive condition.

In order to compare the reproductive performance between wild and pond-reared *L. schmitti* males, the present study analyzes sperm quality of males from both origins, as well as mating success, fertilization rate, and number of nauplii per spawn of pond-reared females mated with wild or pond-reared males. This analysis was done over a production cycle of 70 days to evaluate a possible differential deterioration of reproductive condition between origins.

MATERIALS AND METHODS

Pond-reared females and mature males of southern white shrimp *L. schmitti* were collected in ponds of the hatchery YAGUACAM, (Cienfuegos Province, Cuba). The culture conditions consisted of 0.38-ha-earthen ponds, 1-m deep, and density of 0.5 adults/m^2. Harvesting was done when shrimp were 7 months-old by lowering the water level of the ponds and capturing the animals with a cast net near the exit gate. The shrimp were transferred to the hatchery in plastic buckets during the night. Wild mature males of the same species were captured in the Gulf of Guacanayabo, Granma Province, Cuba by trawling and transferred to the hatchery in 20-L polyethylene bags (5 animals/bag) during the night. Each bag contained an approximate volume of 1/3 seawater and 2/3 oxygen.

Males were maintained separately from females, according to the method recommended by Browdy *et al.* (1996). The males were separated randomly in five different tanks for each origin and stocked at a density of 7 males/m^2. Oval fiberglass tanks were used, with 10 m^3 capacity (surface area 16 m^2). The water volume was maintained at 4 m^3 by means of an overflow system with a daily water exchange of 200%. Aeration was provided with blowers and stone diffusers, and artificial illumination was used with a photoperiod of 14:10 hours (light-darkness). The physical-chemical variables of tank water, temperature, dissolved oxygen, pH, and salinity were measured daily. Some variation of temperature did occur (Fig. 1) because no controlled system for temperature is normally used in the hatchery of Yaguacam.

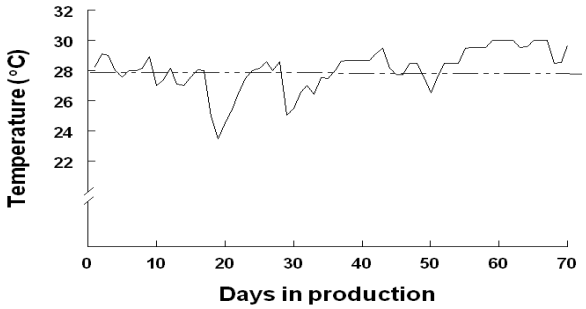

Fig. 1. Daily water temperature over the 70-day production cycle. The discontinues line showed the temperature values over 28°C.

This variation will be analyzed throughout the present work because of its influence on male reproductive performance. Frozen squid (*Loligo sp.*) was provided in three rations at 20% of the total shrimp fresh weight, along with an artificial diet (35% protein, Zeigler Brothers, Inc.) of two rations at 2% of the total shrimp fresh weight. Females at maturation stage IV (Guitart *et al.*, 1988) were placed daily in the tanks with males at a ratio of 10 males to 1 female (12 females in each male's tank). Daily data of percentage of mated females, fertilization, and nauplii per spawn were obtained during a reproduction cycle of 70 days.

Sampling of 15 wild and 15 pond-reared males at intermolt stage was done at 3, 30, and 60 days after acclimation. Male total weight was registered, the hepatopancreas was dissected and weighed, and the spermatophore was manually expelled, weighed and used to assess sperm quality as described below. Tissue somatic index was calculated for the hepatopancreas (HSI) and spermatophores (SSI) as follows: (tissue weight/body weight) x 100.

Sperm quality was assessed by sperm cells count, gross morphology, and using trypan blue biostain reaction for dead sperm cells. Sperm quality was determined using a Neubauer counting chamber, according to the method described by Leung-Trujillo and Lawrence (1987), by homogenizing the spermatophore in a calcium-free saline solution (Composition per 1-l solution: 21.63 g NaCl, 1.12 g KCl, 0.53 g H_3BO_3, 0.19 g NaOH, 4.93 g $MgSO_4 \cdot 7H_2O$, and pH adjusted to 7.4 with 1N HCl). Dead sperm cells were stained with a solution 0.1% trypan blue (Sigma, St. Louis, USA) prepared in calcium-free saline solution that was mixed with sperm suspension in a 1:10 proportion (Leung-Trujillo and Lawrence, 1987) and counting dead sperm cells after 10-15 min. In addition, gross morphology of sperm cells was examined: Sperm cells with a spherical body and an elongate spike were considered normal, whereas abnormal sperm cells were distinguished by malformed bodies or by a bent, short, or missing spike (Leung-Trujillo and Lawrence, 1987).

STATISTICA (version 7.0, StatSoft, Inc. 2001, Tulsa, OK, USA) was used for all analyses. Two-way ANOVA, followed by Tukey's post-hoc mean comparison test was used to assess for significant differences in variables between origins (wild or pond-reared) and sampling periods (1st to 10th week for production variables, and 3, 30, and 60 days for sperm quality). To analyze the relation between spermatophore weight, sperm cells count, normal sperm cells and body weight, correlation analyses were done. When a correlation was significant for wild or for pond-reared males, an ANCOVA analysis was used using body weight as covariable. Correlation analysis between daily productive variables (percentage of mated females and fertilization rate on day X) and water temperature recorded the same day (day X) or one to five days before (X-1 to X-n) was also applied. A chi-squared test was used to assess differences between proportions of males with melanized spermatophore per tank. Results are reported as mean ± standard error. The level of significance was present at $P < 0.05$, $P < 0.01$ and $P < 0.001$ for different analyses.

RESULTS

Body weight was significantly higher in pond-reared than in wild male at the beginning of the production cycle, but it only increased in the later over time (Table 1). For spermatophore weight, a significant main effect of origin was obtained, with higher values for wild shrimp at the beginning of the production cycle, but a significant increase in spermatophore weight was observed for pond-reared shrimp after 30 and 60 days, reaching similar values to those of wild shrimp (Table 1). When body weight was included as a covariable in an ANCOVA analysis, or when spermatophore weight was corrected by body weight to obtain a spermatophore-somatic index (SSI), the main effect of time was no significant (ANCOVA) or was not so evident (lack of difference between means for SSI). However, the difference between wild and pond-reared males was still present and even more accentuated for bigger spermatophores in wild shrimp. The use of the ANCOVA analyses was justified by significant correlations with body weight, and the corresponding regression lines also illustrated the bigger spermatophores in wild males for the whole interval of shrimp body weight (Fig 2A).

Hepatopancreas weight was affected both by origin, with lower values for wild males, and by time, with an irregular pattern depending on origin, as shown by a significant interaction: an increase over time in wild males and a peak at 30 days for pond-reared males (Table 1). However, when body weight was included as a covariable in an ANCOVA analysis or when hepatopancreas weight was

Table 1. Morphometric characterists of wild and pond-reared males sampled at different times over the production cycle.

	3 days	30 days	60 days	ANOVA (ANCOVA) Origin	Time	OxT
Body weight (g)						
Pond-reared	25.2±0.6^{b}	27.2±0.4^{b}	27.1±0.5^{b}	<0.001	<0.001	NS
Wild	22.1±0.8^{a}	24.7±0.6^{ab}	25.1±0.8^{b}			
Spermatopohore weight (mg)						
Pond-reared	54.5±3.3^{a} (54.7)	73.5±3.3^{b} (66.8)	73.8±4.5^{b} (67.6)	<0.001 (<0.001)	<0.001 (0.056)	NS (NS)
Wild	74.4±4.9^{b} (84.8)	89.1±4.8^{b} (90.8)	87.1±4.5^{b} (87.6)			
SSI (%)						
Pond-reared	0.22±0.011^{a}	0.27±0.012^{a}	0.27±0.016^{a}	<0.001	<0.05	NS
Wild	0.33±0.016^{b}	0.36±0.016^{b}	0.35±0.015^{b}			
Hepatopancreas weight (g)						
Pond-reared	0.67±0.031^{ab} (0.67)	0.73±0.023^{b} (0.67)	0.68±0.029^{ab} (0.63)	<0.05 (NS)	<0.05 (NS)	<0.05 (<0.01)
Wild	0.57±0.030^{a} (0.65)	0.63±0.026^{ab} (0.64)	0.73±0.037^{b} (0.73)			
HSI (%)						
Pond-reared	2.67±0.090^{ab}	2.67±0.071^{ab}	2.51±0.091^{a}	NS	NS	<0.01
Wild	2.58±0.088^{ab}	2.54±0.096^{ab}	2.89±0.098^{b}			

SSI: Spermatophore-somatic index, HSI: Hepatopancreas-somatic index.
Two-way ANOVA (or ANCOVA in parenthesis) results are shown in the last columns for Origin, Time in production or the interaction between both factors (OxT). Data are expressed as mean ± standard error, results are indicated (NS: Not significant). Within each row, different letters indicate significant differences ($p<0.05$), n=15 males in each origin and each time of the productive cycle. Adjusted means for body weight resulting from the ANCOVA are shown in parenthesis

corrected by body weight to obtain a hepatopancreas - somatic index (HSI), only the interaction was still significant, with higher values justified by significant correlations between hepatopancreas weight and body weight both for wild ($r = 0.68$, $P<0.05$) and pond-reared ($r = 0.57$, $P<0.05$) shrimp (not shown).

Sperm cells count was generally higher at the middle of the production cycle for both origins, and although no significant interaction between origin and time was found, a different pattern for wild and pond-reared shrimp was observed: the lowest value was at the beginning for pond-reared males and at the end for wild males (Table 2). A significant interaction between both factors was found for percentage of normal sperm cells, with a decrease through time for wild shrimp but no significant differences among the three samplings at 60 days in wild males and the opposite trend for pond-reared males. The ANCOVA analysis was

for pond-reared shrimp (Table 2). Although significant correlations were observed between sperm cells count or proportion of normal sperm cells and body weight for pond-reared males (Fig. 2B and 2C), the ANCOVA analyses using body weight as covariable did not correct for the effects previously described. Percentage of abnormal sperm cells was not affected by time in production or origin of shrimp, while dead sperm cells count significantly increased through time for both origins (Table 2). The proportion of males per tank with melanized spermatophore was significantly higher for wild (4.8%) than for pond-reared shrimp (1.6%; not shown).

Table 2. Sperm quality of wild and pond-reared males sampled at different times over the production cycle.

				ANOVA (ANCOVA)		
	3 days	30 days	60 days	Origin	Time	OxT
Total sperm cells count (10^6)						
Pond-reared	9.7±0.79^{a} (9.8)	20.1±1.51^{b} (19.6)	16.7±1.04^{b} (16.2)	NS (NS)	<0.001 (<0.001)	NS (NS)
Wild	12.4±0.79^{ab} (13.2)	17.8±1.25^{ab} (18.0)	10.5±0.98^{a} (10.6)			
Normal sperm cells (%)						
Pond-reared	77.3±1.28^{ab} (77.3)	80.9±1.48^{ab} (80.7)	78.3±2.23^{ab} (78.2)	NS (NS)	<0.05 (<0.05)	<0.05 (<0.05)
Wild	82.0±0.91^{b} (82.3)	80.9±0.90^{ab} (81.0)	73.9±3.04^{a} (73.9)			
Abnormal sperm cells (%)						
Pond-reared	19.0±1.92	16.8±1.16	17.3±2.87	NS	NS	NS
Wild	15.0±1.87	16.4±2.16	16.5±4.79			
Dead sperm cells count (10^6)						
Pond-reared	0.36 ±0.03^{a}	0.46 ±0.06^{ab}	0.74 ±0.07^{ab}	NS	<0.05	NS
Wild	0.36 ±0.05^{a}	0.5 ±0.04^{ab}	1.0±0.20^{b}			

Two-way ANOVA (or ANCOVA in parenthesis) results are shown in the last columns for Origin, Time in production or the interaction between both factors (OxT). Data are expressed as mean ± standard error, results are indicated (NS: Not significant). Within each row, different letters indicate significant differences ($p<0.05$), n=15 males in each origin and each time of the productive cycle. Adjusted means for body weight resulting from the ANCOVA are shown in parenthesis

Table 3. Correlation coefficients (r) between daily productive variables and temperature recorded the same day (day X) or up to five days (X-1 to X-5) before.

	Day on which temperature record was used for the correlation					
Productive variables on day X:	X	X - 1	X - 2	X - 3	X - 4	X - 5
Mated females (%)						
Pond reared males	- 0.33**	- 0.39***	- 0.35**	- 0.19	- 0.10	0.01
Wild males	- 0.25*	- 0.40***	- 0.38**	- 0.24	- 0.19	- 0.14
Fertilization rate (%)						
Pond reared males	- 0.03	- 0.15	- 0.05	0.03	0.01	- 0.10
Wild males	- 0.30*	-0.41***	- 0.37**	- 0.38**	- 0.33**	- 0.20

* P < 0.05, ** P < 0.01, *** P < 0.001

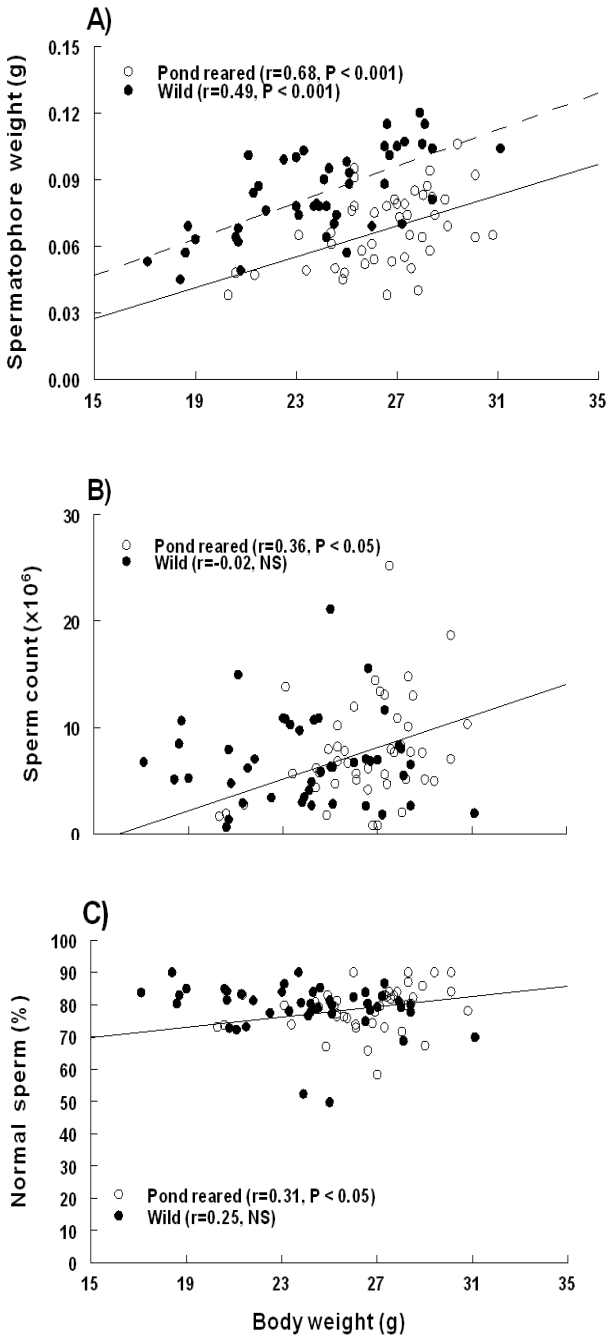

Fig. 2. Correlation between body weight and spermatophore weight (A), total sperm count (B), and percentage of normal sperm (C). Correlation coefficients and significances for wild and pond-reared males are indicated. NS: Not significant

The percentage of mated females was not significantly different when using wild or pond-reared males (Fig. 3A). However, a significant effect of time in production was observed, with higher values five weeks after stocking and a decline towards the end of the period evaluated: No significant interaction was observed between time and origin, but this decline was apparently more pronounced for wild males. Fertilization rate was significantly affected by time and origin, with higher values at the middle of the production cycle (Fig. 3B). Lower fertilization rates were observed for wild males, in particular on weeks 9 and 10. Average nauplii number per spawn was lower at the beginning and at end of the production cycle (Fig. 3C). Nauplii production tended to be lower for females crossed with wild males, mainly towards the end of the production cycle.

The percentage of mated females on day X was significantly correlated to water temperature recorded on the same day (day X) or on the previous two days of the mating for both origins (Table 3). For fertilization rate, the negative correlation with temperature was significantly different only for wild shrimp, with the effect of temperature dating back as long as four days in relation to the day the spawn was produced (Table 3).

DISCUSSION

Wild males were smaller than pond-reared when stocked and this can affect several of the analyzed variables. For example, it is well known that both spermatophore weight and sperm cells count increase with increasing body weight in several penaeid species (Pratoomchat *et al.*, 1993; Rosas *et al.*, 1993; Wang *et al.*, 1995; Ceballos-Vázquez *et al.*, 2003), a result also observed in the present study. We also found an increase in normal sperm cells percentage with larger body weight for pond-reared shrimp, similarly to the results reported by Ceballos-Vázquez *et al.* (2003) for *L. vannamei* and those reported by Alfaro (1993) for *L. stylirostris*. In an attempt to correct for the influence of body weight, an ANCOVA using with body weight as covariable was applied, and it was found that wild males had a larger spermatophore and in general, a smaller hepatopancreas. The hepatopancreas size was a direct consequence of body weight, because the main effect of origin was no significant when using ANCOVA or when hepatopancreas weight was corrected for body weight using the HSI. However, bigger spermatophore weight in wild males at three days after acclimation was partially masked by larger body weight in pond-reared shrimp.

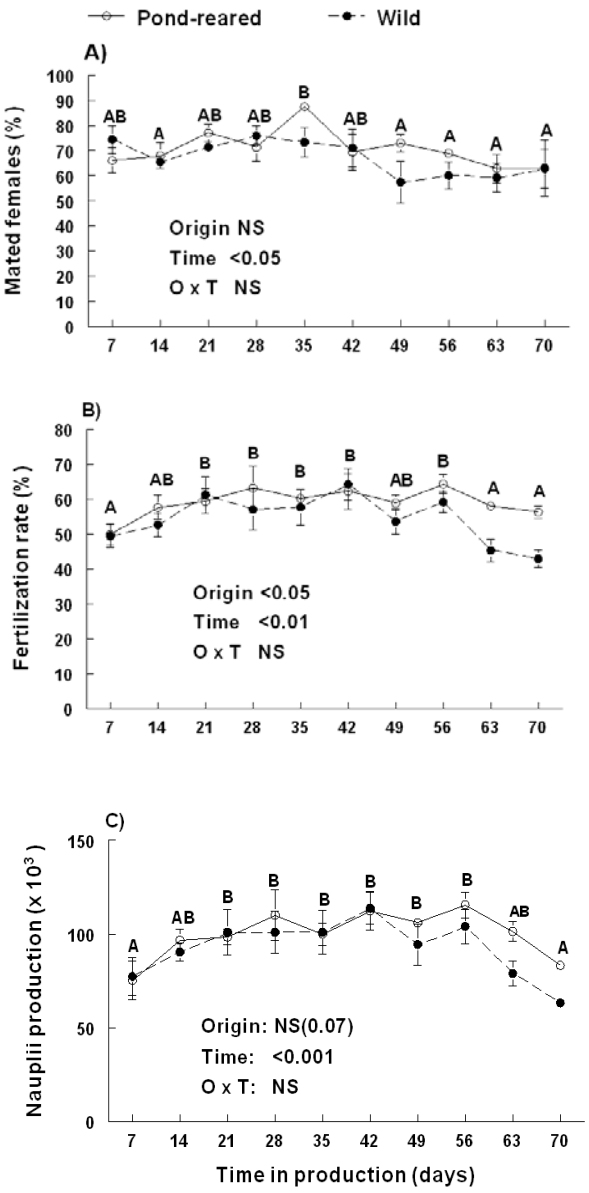

Fig. 3. Production variables over a 10-weeks production cycle of pond-reared females crossed with pond-reared or wild males: A) Percentage of mated females, B) fertilization rate, and C) average nauplii production per spawn. Values are expressed as mean ± standard error; two-way ANOVA (time in production and origin of males) results are indicated (NS: Not significant). Different letters indicate significant differences ($\underline{P}$<0.05).

No differences were observed for sperm cells count between both origins regardless of the ANCOVA correction, so the differences in spermatophore weight must be a result of other factors than sperm mass. We suggest that differences in agglutinating mass exist, which was confirmed by visual observations. However, it was not possible to take photographs of spermatophores or to analyze mucopolysaccharide content, which constitutes this agglutinating mass (Sasikala and Subramoniam, 1987). Wang *et al.* (1995) also concluded that variations in spermatophore weight are more likely a result of differences in structural components and amount of glutinous material, rather than to sperm mass. The quantity of agglutinating mass is involved in the adherence properties of the spermatophore (Pérez-Farfante, 1975; Talbot *et al.*, 1989; Heitzman *et al.*, 1993), so we expected a lower reproductive performance for pond-reared males. However, this was not the case, as the percentage of mated females and other reproductive quality traits, such as fertilization rate and number of nauplii per spawn were no different from wild males. Moreover, fertilization rate was higher in pond-reared shrimp. No differences in sperm quality between wild and pond-reared males were found, although a different response through time was observed but will be discussed below. In accordance, no differences in sperm quality were observed between wild and pond-reared *Penaeus monodon*, despite a larger spermatophore and body size of wild males (Pratoomchat *et al.*, 1993). The comparable reproductive performance of *L. schmitti* pond-reared males clearly justifies their use for larvae production, with all the inherent advantages of using cultivated stocks (for review see Browdy, 1998; Racotta *et al.*, 2003).

The general pattern of reproductive performance was a decrease over time in production, which corresponds to the well known phenomena of reproductive exhaustion, abundantly reported for female-related variables (for reviews see Racotta *et al.*, 2003). Although no significant interaction was observed, this decrease appears to be more pronounced in wild males, and corresponds to lower values of total sperm cells count and normal sperm cells percentage, together with higher values of dead sperm cells in wild males at the end of the production cycle. Thus, at least part of the reproductive exhaustion during the production cycle is a result of decreased male quality. A decline in sperm quality through consecutive spermatophore regenerations over time has been

reported for *L. setiferus* (Leung-Trujillo and Lawrence, 1987; Talbot *et al.*, 1989; Rosas *et al.*, 1993; Pascual *et al.*, 1998). However, this was not the case for other open- and closed-thelycum species, such as *L. stylirostris* (Alfaro, 1993), *P. monodon* (Gomes and Honculada-Primavera, 1993; Pratoomchat *et al.*, 1993), and *L. vannamei* (Leung-Trujillo and Lawrence 1985, Alfaro and Lozano, 1993; Ceballos-Vázquez *et al.*, 2004). However, despite no changes in sperm cells count and abnormalities over consecutive regenerations during one month, Alfaro and Lozano (1993) observed an increase in spermatophore melanization in *L. vannamei* when sampled after three months. The incidence of melanized spermatophores was also higher for wild males in the present study. Two main causes for decrease in sperm quality or melanization of spermatophores have been proposed: a lack of spermatophore transfer to females that results in a natural degeneration process (Alfaro and Lozano, 1993), or high temperatures (Bray *et al.*, 1985; Pascual *et al.*, 1998; Pérez-Velazquez *et al.*, 2001; Pascual *et al.*, 2003). The first explanation does not apply to the conditions of the present study, where males were continually in the presence of females and the mating success was relatively high. However, high temperatures, particularly towards the end of the production cycle (Fig. 1) could explain the decrease in sperm quality (decreased percentage of normal sperm cells and increased dead sperm cells count), particularly for wild males. These results are in agreement with a stronger deterioration of immunological and metabolic condition of wild males compared to pond-reared ones (Pérez-Jar *et al.*, 2006).

The correlation analyses between temperature and productive variables also support the hypothesis of a higher susceptibility in wild shrimp; however, a brief explanation of the meaning and scopes of these analyses should be first stated. Correlation between water temperature and nauplii per spawn was not analyzed because too many mixed effects exist, i.e. temperature can affect several processes that are additive for final value of nauplii per spawn, such as fecundity, embryo development, hatching, etc. For mating success and fertilization rate it is assumed temperature recorded the same day had a direct effect on these variables, but when using temperatures recorded one to several days before, it is assumed they have an effect on sperm production and final quality. The effect of water temperature on sperm quality is supported by the negative correlation between fertilization rate and water temperature of four days before mating. The deterioration of sperm quality in *L. setiferus* was observed as soon as two days after a temperature increase from 31 to 33°C (Pascual *et al.*, 2003), reinforcing our hypothesis on a short term basis. Pérez-Velazquez *et al.*, (2001) in *L. vannamei* observed that adequate sperm cells count and percentage of abnormal sperm cells can be maintained at water temperature of 26 °C, but not at 29 °C or 32 °C. The correlation for fertilization rate were significantly different only for females crossed with wild males, which further confirms a more pronounced influence of temperature on wild males. A higher susceptibility of wild males to high temperatures could be the result of a pre-adaptation of pond-reared shrimp to these conditions that occur normally in ponds.

CONCLUSIONS

The decline in reproductive performance of *L. schmitii* over time is not due to a low reproductive potential of pond-reared shrimps, corresponds to the well known phenomena of reproductive exhaustion. Wild males were more affected by maturation conditions, in terms of overall reproductive performance and sperm quality, possibly as a result of high temperatures during production (≥29°C).

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