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Comparisons in geese of the courtship, mating behaviors and fertility of the Carlos and Sichuan breeds and the breed crosses

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ABSTRACT

The Chinese goose originated from the swan goose (*Anser cygnoides*) and the European goose originated from the greylag goose (*Anser anser*). The Chinese and European geese have the potential to crossbreed. Whether interspecific differences in mating behaviors affect successful hybridization is unknown. In this study, 10-month-old Carlos geese (n = 120; *Anser anser*) and Sichuan geese (*Anser cygnoides*) were selected, and 12 multi-male parent families (3♂ + 12♀) were established. The courtship and mating behaviors of pure and cross-bred combinations of the Carlos and Sichuan geese were recorded using video cameras. Initiative courtship by males was the main type of courtship. Fixed mating, mating interference, and uncooperative mating were common in the flocks. The frequencies of some courtship and mating behaviors were less in the cross-bred groups (Carlos ganders × Sichuan geese, Sichuan ganders × Carlos geese) compared with the Sichuan pure-bred groups ($P < 0.05$). The Carlos male geese had some unique mating behaviors (i.e., one-to-one mating, formation of distinct hierarchies, and competition interference). The fertility rate had a significant correlation with the frequency of successful mating ($r_p = 0.992$, $P < 0.05$), rather than with the courtship behavior. These results indicate there were lesser frequencies of courtship and successful matings in the cross-breeding than purebreeding groups. Furthermore, the fertility rate depended largely on the successful mating behavior and was independent of the courtship behavior.

1. Introduction

Cross breeding was used for attaining more rapid growth rates and greater meat production performance in meat-producing fowl (Huang, 2013; Khawaja et al., 2016; Zhe et al., 2017). Courtship and mating behaviors effectively ensure normal reproduction performance in animals. These relationships have been extensively studied in reptiles (Montanarin et al., 2011), mammals (Miller, 2007), and birds (Fernie et al., 2008). There, however, are relatively few studies on courtship and mating behaviors in chickens and quail (Ottinger et al., 1982; Zuk et al., 1990). Like other fowl, the mating behavior of domestic geese consists of three successive

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sequences, courtship (strutting, pecking the chest, neck, and head of females), copulation attempts (mounting and treading), and successful copulation (cloacal contact and ejaculation) (Gillette, 1977; Gumulka and Rozenboim, 2013). Mating frequency, however, varies with the different goose breeds. In general, the Chinese geese mate successfully a mean of 2.5–5.5 times per day (Wei, 1994; Jing et al., 2010). In European geese, however, the mating frequency/day averaged 2.4 times for the gander and 15.4% of geese were monogamous (Pashchenko and Khranovskii, 1971). In flocks of birds with competitive social mating structures, production success depends on factors associated with sexual and social behavioral interrelationships between potential mates.

Courtship and mating behavior success not only maintains populations and sustains animal production; it also contributes to successful fertilization. Greater copulation frequencies are associated with greater probabilities of successful egg fertilization. Lesser fertility is related to lesser copulation frequencies and plasma testosterone (T) concentrations (Gumulka and Rozenboim, 2013).

To improve the body weight, the cross-breeding between different goose breeds has become one of the important methods to improve the economic efficiency of goose breeding in commercial flocks except for pure breeds in China. These body weights are greater in the animals that result from cross-breed of Huoyan ganders (*Anser cygnoides*) and Sichuan geese (*Anser cygnoides*) or Landes ganders (*Anser anser*) and Yangzhou geese (*Anser cygnoides*) compared with the purebred pairings (Sun et al., 2015; Zhe et al., 2017). The relatively greater slaughter yields of offspring derived from crosses between Canadian ganders (*Branta canadensis*) and White Koluda (*Anser anser*) geese indicate the heterosis that can result from these combinations (Kowalczyk et al., 2013). In a previous study, offspring from the Carlos gander (*Anser anser*) × Yangzhou goose (*Anser cygnoides*) matings had greater heterosis (Su et al., 2015). The fertility rate, however, was less compared with that of the pure-breeding matings. Domestic geese originate from intraspecific grey goose (*Anser anser*) or swan goose (*Anser cygnoides*), hence, the cross-breeding between these two species not only results in a great amount of heterosis for body weight and slaughter yield but also leads to mating dysfunctionality to some extent.

Although the behaviors of courtship and mating of the geese of Chinese (*Anser cygnoides*) or European (*Anser anser*) breeding have resulted in assessing the behaviors of the reciprocal cross of the Chinese and European geese there are not well documented results from studies assessing these behaviors. To investigate the mating behaviors between interspecific hybridization and intraspecific hybridization of geese, the Carlos (*Anser anser*) and Sichuan (*Anser cygnoides*) geese were raised and the courtship and mating behaviors were observed. Furthermore, the relationships between these courtship and mating behaviors and fertility were analyzed. Results provide important data for the improvement of fertility rate among the different goose species used for food production in future.

2. Materials and methods

All bird handling protocols were approved by the Yangzhou University Ethics Committee on Animal Experiments (Permit number SYXK (Su) IACUC 2014-0029; Jiangsu, China). All experimental procedures with geese were performed in accordance with the Regulations for the Administration of Affairs Concerning Experimental Animals, approved by the State Council of the People's Republic of China.

2.1. Animals and experimental design

The study was performed at the National Waterfowl Germplasm Resources Pool (Taizhou, China) from 10 March to 10 April 2016. Twelve multi-male parent families (3♂ + 12♀) were established from 10-month-old Carlos geese (*Anser anser*) and Sichuan geese (*Anser cygnoides*). The breeding groups were Carlos ganders × Sichuan geese (crossbred group, KC), Sichuan ganders × Carlos geese (reverse crossbred group, CK), Carlos ganders × Carlos geese (purebred group, KK) and Sichuan ganders × Sichuan geese (purebred group, CC). There were three replicates per group. All females were fecund birds, were of a similar size, and were clean with healthy plumage. All males were sexually mature and had well-developed genital organs.

All geese were provided with the same diet (Crude protein: 17%, Metabolizable energy: 10.45 MJ/kg), which was combined with coarse and concentrated material and fed ad libitum. The geese were housed in pens (1.5 individuals per square meter) that included a "playground" and "pool" area. Daylight hours were from 6:00 a.m. to 9:00 p.m. Colored paint was used to mark the necks and backs of the geese and to identify the birds during observations of courtship and mating behaviors.

2.1.1. Recording of behaviors and observation

A video camera (Jindun, 720p, Nanjing, China) was positioned above the water surface and land area in the pen of each group. The sexes of geese were isolated for 10 days and then were combined into the family groups to observe courtship and mating behaviors. Observations of sexual behaviors were recorded from 6:00 a.m. to 6:00 p.m. every day for 14 days from 21 March to 3 April 2016. Staff personnel activity inside and outside the pens was minimized to avoid disturbing the geese during the observation period.

During the observation period, a total of 168 h of records was collected for each group. The information recorded from the video data included the behaviors, frequencies, and times of courtship and mating. Defined behaviors were used to determine whether courtship and mating activities occurred (Table 1).

2.1.2. Fertility rate

After 14 days, the eggs from each group were collected for hatching. The egg fertility rates were calculated for each group. Fertility was estimated on the ninth day of incubation after egg candling and was also assessed via verification of a visible blastoderm/blastodisc. Eggs containing embryos developed normally, and the blood vessels were radially distributed and were bright red.

Table 1
Description of criteria for the behavior of courtship and mating activities.

Behavior	Definitions
Initiation of courtship by males[a]	Gander expressed exaggerated walking and approached females and then lightly preened her neck or back feathers, gander-goose chase each other during the encounter
Initiation of courtship by females[a]	Sometimes, Female initiated the approach of the male and pecked his chest, neck and head or plays around the male in water
Male-female mutual courtship[a]	Gander and goose repeatedly thrusts the head and neck towards each other and display a willingness to copulate
Mounting[b]	Gander approached a crouched female from the front of her body or forced her down and placed one/both feet on the dorsal surface of her torso
Successful copulation[b]	After mounting, gander appeared to make cloacae contact with the goose; Tail of male was twisted underneath that of the female and there was a thrust towards her
Female accepted mating[a]	Female accepted the courtship of males and successful mating occurs
Fixed mating with female[a]	In each group (three males and 12 females), the ganders mated with a specific female
Unsuccessful mating[a]	Unsuccessful mating included mating interference by male and uncooperative mating; Mating interference by male means the ganders interrupt the mating through grabbing, repelling, or fighting, which result in the unsuccessful copulation; Uncooperative mating was when some females or males refused to mate, which also resulted in mating failure
Total mating	Calculation of total matings included successful matings and unsuccessful matings

Note:
[a] Defined according to the behavior observed in this study.
[b] Adapted from Gumulka and Rozenboim (2013).

Eggs with embryos were bright in color, had no vascular network and only a yolk shadow. Eggs containing dead embryos were light in color, had irregular blood arcs, blood rings, and no radial blood vessels. The fertility rate was calculated based on the results of candling.

2.2. Statistical analysis

The SPSS software (SPSS, Ver. 17.0 for Windows, 2008) was used for the statistical analysis. The homogeneity test of variance was performed, and the behavior frequency data were assessed using non-parametric methods (Kruskal-Wallis H-test or Chi-square test). The Pearson correlation was used to assess fertility rate, laying rate and mating behaviors. All results are presented as the mean ± standard deviation (SD) of the mean values.

3. Results

3.1. Courtship behaviors of the reciprocal crosses between Sichuan geese and Carlos geese

During the courtship, the geese expressed behavioral characteristics of exaggerated walking, pecking or thrusting the head and neck. Three kinds of courtship behaviors were observed (i.e., initiative courtship by males (0.93–5.07 times/day), initiative courtship by females (0 to 0.36 times/day), and male-female mutual courtship (0.15 to 0.64 times/day)) (Table 2). Initiative courtship by males was the most common courtship characteristic recorded. The frequencies of initiative courtship by males were 0.93 and 0.71 times/day in the cross-breeding groups of KC and CK groups, which were less compared with the frequencies in the pure-breeding groups of Sichuan geese. There were also frequencies of courtship and initiative courtship in the pure-breeding groups of Carlos geese. Initiative courtship by females did not occur in the CK groups.

The data for results of durations of courtship behaviors for the groups are presented in Table 3. The mean duration of initiative courtship by males in the KC groups was longer compared with the CC groups and CK groups.

Table 2
Frequencies (mean ± SD) of courtship behaviors in purebred and crossbreeding groups of geese (n = 180).

Groups	Initiation of courtship by males (times/day)	Initiation of courtship by females (times/day)	Male-female mutual courtship (times/day)
KC	0.93 ± 0.75^{B}	0.07 ± 0.17	0.15 ± 0.30
CK	0.71 ± 0.79^{B}	0.00 ± 0.00	0.29 ± 0.45
KK	1.00 ± 0.84^{B}	0.36 ± 0.61	0.43 ± 0.62
CC	5.07 ± 1.87^{A}	0.21 ± 0.41	0.64 ± 0.89
x^2	28.99	5.03	2.83
$P(df)$	0.00(3)	0.17(3)	0.42(3)

Note: Courtship behaviors were observed using video recordings, and the daily records were recorded from 6:00 a.m. to 6:00 p.m. for 14 days; Each group contained three males and 12 females, three repeats per group; KC: Carlos goose ♂ × Sichuan goose ♀, CK: Sichuan goose ♂ × Carlos goose ♀, KK: Carlos goose ♂ × Carlos goose ♀, CC: Sichuan goose ♂ × Sichuan goose ♀; ^{A,B}Different letters in columns indicate differences ($P < 0.01$).

Table 3
Durations (mean ± SD) of courtship behaviors in groups of purebreeding and crossbreeding geese (n = 180).

Courtship types	Groups	Duration time (s)	Range (s)
Initiation of courtship by males	KC	34.96 ± 20.98[a]	11-96
	CK	17.86 ± 8.85[b]	8-35
	KK	29.25 ± 23.08[ab]	13-69
	CC	20.10 ± 13.36[b]	3-66
Initiation of courtship by females	KC	———	———
	CK	———	———
	KK	36.33 ± 22.48	18-68
	CC	26.00 ± 1.00	13-40
Males-female mutual courtship	KC	43.25 ± 19.61	19-68
	CK	32.00 ± 30.24	9-84
	KK	36.67 ± 20.14	20-65
	CC	28.63 ± 13.34	17-62

Note: Courtship behaviors were recorded from 6:00 a.m. to 6:00 p.m. for 14 days using video recordings, and the durations of courtship behaviors were calculated; [a,b]Different letters in columns indicate differences ($P < 0.05$).

3.2. Mating behaviors of the reciprocal crosses between Sichuan geese and Carlos geese

Some ganders did not mate with the females. Two, one and one ganders in the KC, CK, and KK groups, respectively, did not mate. A completed mating included mounting and copulation. The results of a comparison of the frequencies of mating in each group (excluding males that did not mate) indicated that the mean male mating frequencies were 0.5–1.98 times per day (Table 4). As with courtship, the mean frequencies of successful mating were less in the KC, CK, and KK than the CC groups. Some females were unwilling to mate with males (uncooperative mating, Fig. 1A), but most of the females were cooperative and actively raised their tails during courtship (Fig. 1B). The data for results for duration of mounting and copulation in the groups are presented in Table 5, and there were no significant difference of the two behaviors among the four groups ($P > 0.05$).

Some ganders had fixed mating habits. Each male mated with two to eight females in the CC groups, and each male only mated with one to three females in KK groups. The KC group males mated with a mean of five females and the reverse cross group (CK) males mated with a mean of two females (Table 6). Furthermore, there was a pairing of ganders with a single goose (gander only mated with the goose, and goose only mated with the gander, i.e. monogamy) in the KK groups.

A special mating behavior was recorded such as mating interference. Some males effectively stopped other pairs from mating using grabbing, repelling, or fighting actions (mating interference, Fig. 1E). As many as 12.5% of the total mating activity (the total of successful and unsuccessful matings) in the pure-breeding Carlos geese groups consisted of mating interference, which was more than twice as great (4.3%) in the pure-breeding groups of Sichuan geese (Table 6). Hierarchical mating behavior rank was recorded in the Carlos geese group; one gander mated preferentially. After the dominant male was removed, the two remaining males began to mate successfully. The analysis of mating preferences for the Carlos ganders indicated there was a general preference of ganders for clean, healthy, and willing females and that females preferred males that mated more often and displayed behaviors that indicated a strong mating desire. When the male mounted the back of the female and was ready to mate, the other flock members approached the pair with extensive vocalization (recorded as "squabbling"; Fig. 1D).

A flow chart of courtship and mating behaviors was established according to the proportion and duration of different behaviors during the mating process (Fig. 2). Males failed to mate due to incompatibility with females or interference by other males during the mating process. The rates of successful mating in the cross-breeding groups were less compared with the rates in the Sichuan goose pure-breeding groups.

3.3. Relationships between courtship, mating activity and fertility, and laying

The data for results from the analysis of fertility and laying rates in the different groups for the 14-day observation period are

Table 4
Frequencies (mean ± SD) of mating behaviors in groups of purebreeding and crossbreeding geese (n = 180).

Groups	Mounting (times/day)	Copulation (times/day)	Female accepted mating (times/day)	Mating frequency (times/one goose*day)
KC	1.50 ± 1.07[bc]	1.21 ± 0.90[b]	1.07 ± 0.86[b]	1.14 ± 0.83[b]
CK	1.29 ± 0.88[c]	1.14 ± 0.99[b]	0.79 ± 0.77[b]	0.50 ± 0.42[c]
KK	2.29 ± 1.03[b]	2.00 ± 0.84[b]	1.64 ± 0.89[b]	0.89 ± 0.39[bc]
CC	6.64 ± 2.46[a]	6.14 ± 2.53[a]	5.64 ± 2.66[a]	1.98 ± 0.83[a]
x^2	33.13	32.22	32.76	23.83
$P(df)$	0.00(3)	0.00(3)	0.00(3)	0.00(3)

Note: Mating behaviors were observed using video recordings, and the daily records were recorded from 6:00 a.m. to 6:00 p.m. for 14 days; Each group contained three males and 12 females, three repeats per group; [a,b]Different letters in columns indicate differences ($P < 0.05$).

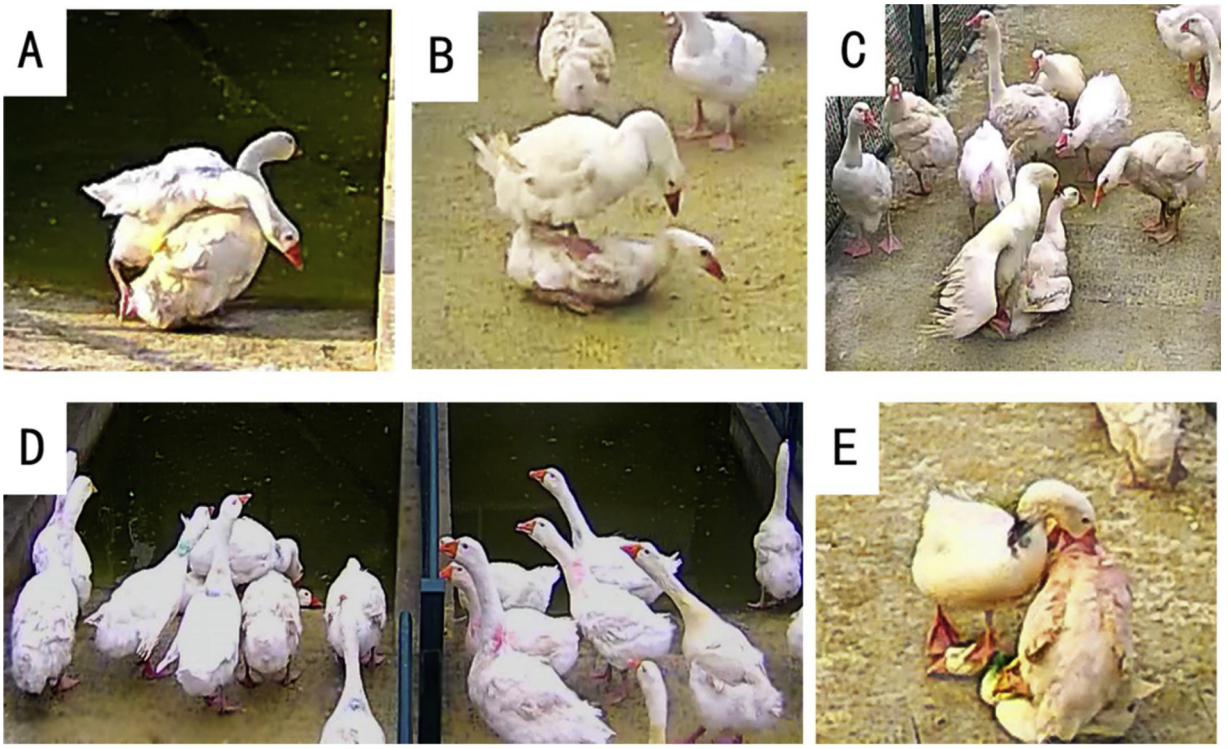

Fig. 1. Observed typical mating behaviors of Carlos and Sichuan geese. Mating behaviors in the goose flock were observed and video recorded. Typical behaviors were A. mounting (female rejected mating); B. mounting (female accepted mating); C. copulation; D. squabbling; E. mating interference.

Table 5
Durations (mean ± SD) of mating behaviors in groups of purebreeding and crossbreeding geese (n = 180).

Groups	Mounting (s)		Copulation (s)	
	Duration	Range	Duration	Range
KC	14.94 ± 10.36	2-38	6.13 ± 4.66	3-22
CK	8.36 ± 6.30	2-25	6.10 ± 4.70	3-20
KK	13.00 ± 11.00	3-46	6.20 ± 1.90	3-10
CC	11.94 ± 7.67	3-44	5.01 ± 2.71	2-18

Note: Mating behaviors were recorded from 6:00 a.m. to 6:00 p.m. for 14 days using the video recordings, and durations of mating behaviors were calculated.

Table 6
Special mating behaviors in groups of pure-bred and crossbred geese (n = 180).

Groups	Fixed mating with female[a]	Mating interference by male[b] (%)	Uncooperative mating[c] (%)
KC	5.00	9.5	14.3
CK	2.00	5.6	16.7
KK	1.50	12.5	9.4
CC	5.67	4.3	6.5

Note: Special mating behaviors were recorded including the fixed mating with females, mating interference by males and the uncooperative matings.

[a] Ganders mated with specific females and average number of females of every group was calculated.

[b] Ganders interrupted the mating by grabbing, repelling, or fighting, which resulted in the unsuccessful copulation and the proportions were calculated.

[c] Some females or males refused to mate, which also resulted in mating failure; Data shown are means and the proportions were calculated.

presented in Table 7. Sichuan goose egg production was almost two times greater compared with that of the Carlos geese. The fertility rates for the CC, KK, KC, and CK groups were 97%, 74%, 62%, and 60%, respectively. The mean laying rates for the CC, KK, KC, and CK groups were 25%, 9%, 11%, and 21%, respectively.

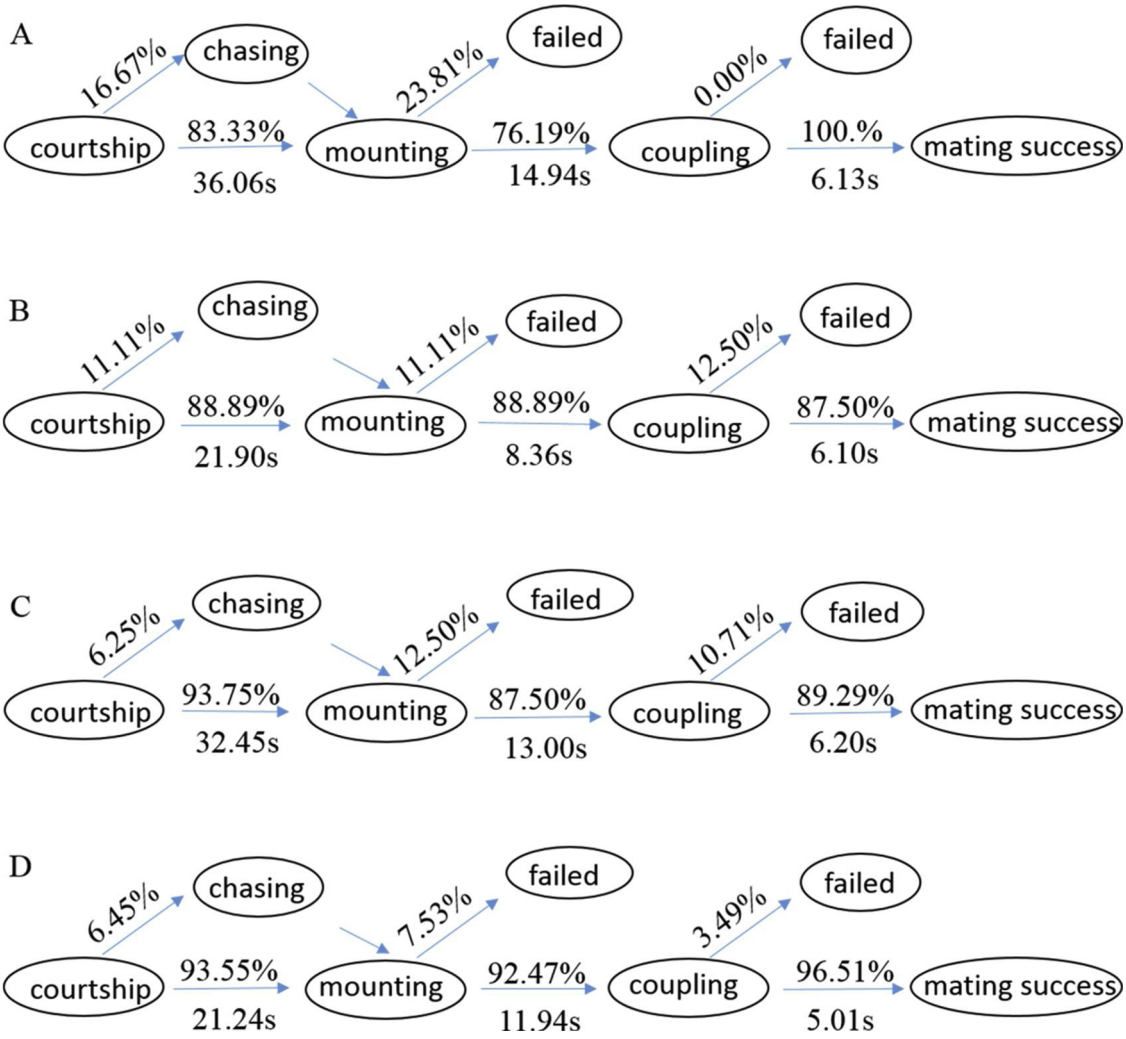

Fig. 2. Flow chart of courtship and mating behaviors observed in groups of pure and cross-breeding groups of geese. A total of 83.33%, 88.89%, 93.75%, and 93.55% of the courtship behaviors were converted into mounting in Carlos goose ♂ × Sichuan goose ♀ (A), Sichuan goose ♂ × Carlos goose ♀ (B), Carlos goose ♂ × Carlos goose ♀ (C) and Sichuan goose ♂ × Sichuan goose ♀ (D), respectively. A total of 100.0%, 87.5%, 89.29%, and 96.51% of coupling behaviors were converted into successful mating in Carlos goose ♂ × Sichuan goose ♀ (A), Sichuan goose ♂ × Carlos goose ♀ (B), Carlos goose ♂ × Carlos goose ♀ (C) and Sichuan goose ♂ × Sichuan goose ♀ (D), respectively.

Table 7
Laying and fertility rates (mean) for groups of purebreeding and crossbreeding geese.

Groups	KC	CK	KK	CC
Fertility rate (%)	62	60	74	97
Laying rate (%)	25	9	11	21

Note: Laying eggs were collected during the continuous 14 days and the fertilization of eggs was evaluated via verification of a visible blastoderm/blastodisc after the incubation period.

Correlation analyses were performed between fertility rate and the courtship and mating behaviors and between laying rate and the courtship and mating behaviors (Table 8). The results indicated that fertility rate was significantly and positively correlated with the total frequency of mating and the frequency of successful mating ($P < 0.05$), not with frequency of courtship behaviors. The correlations between laying rate and the frequencies of courtship and mating behaviors were not statistically significant.

Table 8
Correlation coefficients between fertility rate, laying rate, and courtship and mating behaviors (n = 180).

Project	Frequency of initiation of courtship by males	Frequency of initiation of courtship by females	Frequency of male-female mutual courtship	Frequency of total mating	Frequency of successful mating
Fertility rate	0.776	0.745	0.731	0.905	0.992*
Laying rate	0.408	−0.107	−0.079	0.351	0.353

Note: Fertility and laying rates were calculated as a result of observations for 14 days; Data in the table are Pearson correlation coefficients.
* Indicates significant correlation at the 0.05 probability level (two-tails).

4. Discussion

4.1. Courtship behavior of the reciprocal crosses between Sichuan and Carlos geese

Animal courtship behavior is an important reproductive behavior for attracting the opposite sex to complete mating. Animal courtship can occur through vocalizations, physical display, specific behavior expressions, nesting and some other means (Ota et al., 2015). In the present study, the goose expressed the behavior characteristics of strutting with head held high, pecking or thrusting the head and neck during the courtship. The three types of courtship in the goose flocks (initiative courtship by males, initiative courtship by females, and male-female mutual courtship) were observed. Initiation of courtship by males was the most frequent type of courtship. This finding is consistent with results from a previous study (Jing et al., 2010) of courtship behavior of Magang Geese. In the previous study, the mating was dominated by males and most females were submissive or compromised after resisting. This result is consistent with the hypothesis of compulsory male behavior and guaranteed fertilization and access to quality genes for females (Liu, 2002). The frequencies of initiative courtship by males and male-female mutual courtship in the cross-breeding groups were less compared with those in the pure-breeding groups. The Sichuan geese and Carlos geese in the present study originated from *Anser cygnoides* and *Anser anser*, respectively. The results suggest that there were a low interspecies affinity between *Anser cygnoides* and *Anser anser* resulted in lesser gander–goose interactions.

4.2. Mating behaviors of the Sichuan and Carlos geese reciprocal crosses

Similar to the findings for courtship, the frequencies of successful mating were less in the cross-breeding groups (KC, CK) compared with the pure-breeding groups of Sichuan geese. The results suggest that a lesser interspecies affinity resulted in a reduction in not only the frequencies of courtship behaviors, it also resulted in a decrease in the frequencies of mating behaviors. Taken together, the results indicate that to improve the production performance (e.g., increase mating rates) of crosses between the Chinese goose and European goose, ganders and females should be grouped as early as possible before sexual maturity. The sex ratio should also be less than one male to three females in a flock of geese. Reducing the sex ratio to less than one male to three females can lead to increased behavior associated with competition between males. Of course, the effectiveness of mating might be reduced with this approach. The pure-breeding groups of Carlos geese also had lesser mating frequencies. This result was due to the effects of the hierarchic rank and mating interference that was common in the Carlos goose flocks. The results indicate that the rates of successful mating can be improved by removing individuals that display selective mating behaviors during the European goose production process. The numbers of matings per day (0.50–1.98/day) that were observed in the present study were less compared with that reported in other studies (Pashchenko and Khranovskii, 1971; Gillette, 1977; Pan and Chen, 1994; Jing et al., 2010). This difference was likely due to the use of the video system, which would have enabled detection of relatively more of the mating failures.

4.3. Relationships between courtship, mating activity and fertility, laying

In the present study, the relationship between mating activity and fertility, laying within 14 days was assessed. There was a significant correlation between the fertility rate and the frequency of successful mating, rather than with total frequencies of mating. This finding is consistent with the results of previous studies where there was no relationship between the mating frequency and fertility in competitive mating environments (Rosiński, 1986). Furthermore, Raud and Faure (1990) also reported the daily rhythm of mating activity did not coincide with the optimal female fertility in Muscovy ducks. Bilcik and Estevez, (2005) emphasized that fertility of each male is relative to mating strategy (i.e. individual housing with harem or with other competitor males) in flocks of meat-type chickens. In the present study, there was frequent mating competitive interference by males in the goose flocks, which led to unsuccessful mating and lesser fertility rates. This might be one of the main reasons why the total mating frequency was not related to the fertility rate in the present study. In husbandry conditions, domestic geese are bred to mate promiscuously. It, therefore, is not feasible to improve the population fertility rate simply by increasing the frequency of mating. In the present study, however, there was a significant positive correlation between frequency of successful mating and fertilization. Similar results were reported by Gumulka and Rozenboim (Gumulka and Rozenboim, 2013, 2015) where frequency of successful mating was used as an index to estimate the reproductive potential of males. In domestic goose flocks, reproductive success is associated with the age of ganders (Gumulka and Rozenboim, 2017), which is probably due to the multifactor effect of interaction between sexual/social experience; therefore, it is recommended to mate pubescent geese with older ganders that have more sexual experience for optimal fertility results.

In addition, the egg production had no obvious relationship to the frequency of courtship and mating. Egg production, of course, was measured in females, and the initiative courtship and mating behaviors mainly results from gander behaviors. It, therefore, is reasonable that there was no correlations between laying rate and courtship and mating behaviors. There were some reports that the receptivity to courtship and mating behavior of a male was associated with the position of the eggs in the oviduct and the times of oviposition in domestic hens (Brillard et al., 1987) and ducks (Raud and Faure, 1990). In this regard, the courtship and mating behaviors had no effect on egg production.

5. Conclusions

In conclusion, in the present study the initiation of courtship by males was the main type of courtship expressed. Monogamous mating, mating interference, and uncooperative mating behaviors were common in the goose flocks. The frequencies of courtship and successful mating in the cross-breeding groups (Carlos ganders × Sichuan geese, Sichuan ganders × Carlos geese) were less than those in the pure-breeding groups (Sichuan ganders × Sichuan geese). The results indicate that lesser interspecies affinity between the *Anser cygnoides* and *Anser anser* breeds results in lesser gander–goose interaction than occurs with some other breeds. Fertility rates were positively correlated with the frequency of successful mating. Fertility rates can be improved by increasing the frequencies of successful mating in goose production enterprises. The results of the present study also indicate there are differences in courtship and mating behaviors between Sichuan geese and Carlos geese and provides a theoretical basis for scientific selective breeding and increasing waterfowl productivity for inclusion in human diets.

Author contributions

Y Zhang and Y Yao analyzed the samples and wrote the manuscript; M.M Wang helped to raise the experimental animals; Y.Z. Yang and Z.F. Cao performed the statistical analyses; T.T Gu, L.Lu and C An collected the samples; W.M Zhao, J.W Wang and G.H Chen helped elaborate the methodologies; Q Xu. is responsible for the design, supervision and coordination of the project. All authors read and approved the final manuscript.

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Conflicts of interest

None.

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