Sustainable Snakehead Aquaculture Development in the Lower Mekong River Basin of Cambodia

Indigenous Species Development/Experiment/ 13IND02UC

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ABSTRACT

Farming snakehead is prohibited in Cambodia due to its dependence on freshwater small-sized fish (FSF) for sourcing key dietary nutrient inputs and seed collected from the wild, while lack of technologies on developing of snakehead hatcheries through breeding, weaning, and grow-out on formulated or pelleted diets. This study was conducted to investigate weaning and grow-out performance of the wild indigenous *Channa striata* (non-domesticated) in Cambodia compared to those of domesticated snakehead imported from Vietnamese hatcheries on formulated or pelleted feed (FF or PF) and to assess economic efficiency and product quality of the two types of snakehead fed on different diets at the end of experimental grow-out. In the experiment 1 (weaning): three day-old larvae of both types of both *C. striata* were stocked in 50 L-tank at a density of five fish L-1 and fed on Moina, FSF, and FF (45% CP) to satiation four times daily for 45 days. In experiment two (grow-out): the experiment was conducted in 18 hapa-nets (1.8m x 2.5 m x 1.8 m) placed in three earthen ponds (300 m^2 each) at a density of 100 fingerlings hapa-1 (three replicated hapas for domesticated fingerling and three replicated for non-domesticated). Snakehead fingerlings (12-13 g fish-1) were fed on three diets: 1) FSF (Pond 1); 2) PF (40% CP, Pond 2); and 3) 50:50 mixtures of FSF and PF (Mix, Pond 3). The fish was fed to satiation twice daily for six months. The results of the study showed that weaning of non-domesticated and domesticated *C. striata* larvae on FF can start at 17 days after hatch with replacement ratio 10% FF day-1 for substituting FSF. Feed intake (107 mg fish-1 day-1) and final weight (170 mg) of domesticated snakehead was higher than the ones (85 mg fish-1 day-1 and 146 mg, respectively) of non-domesticated snakehead, while survival rate (29%) and cannibalistic rate (47%) of the domesticated was lower than the ones (36% and 51%, respectively) of the non-domesticated. In grow-out experiment, both snakeheads can accept formulated or pelleted feed. However, the domesticated snakehead showed higher survival rate (75%), better growth performance (final body weight 367 g fish-1), higher feed intake (3 g fish-1 day-1), and food conversion ratio (FCR; 1.5) than the non-domesticated snakehead (69% and 233 g fish-1, 2 g fish-1 day-1 and 1.7, respectively) since the domesticated hatchery snakehead has gone through more than two-decade domestication. Considering economic efficiency, replacing freshwater small-sized fish by pelleted feed up to 100% is possible and profitable for both snakeheads. However, the domesticated snakehead (about US$ 0.35/kg fish produced) showed higher profit than the non-domesticated snakehead (US$ 0.25/kg fish produced). In regards to product quality, pelleted feed does not significantly affect the fillet quality of both cultured snakeheads compared to a diet of FSF and a mixture.

INTRODUCTION

In Cambodia wild snakeheads are generally cultured in smaller cages and ponds. Feed represents more than 70% of the total operational cost and the main type of feed for wild snakehead culture is small-sized or low -value fish, representing 60 to 100% of the total feed used depending on feeding strategies adopted by different farmers (So et al. 2005). During the dry season (October to May), the most important source of feed is freshwater small-sized or low-value fish, while more marine small-sized or low-value marine fish species are used during the rainy season (June to September) (So et al. 2005). Importantly, the snakehead production contributes more than 70% of total aquaculture production in Cambodia due to its popularity as food and high market and trade demand in Cambodia as well as in Vietnam, being found in most Cambodian and Vietnamese dishes at all wealth class levels (i.e. from poor, medium, to rich people). During the first phase of AquaFish CRSP (2007-2009), the Investigation # 2 revealed that nearly 200 freshwater small-sized fish species were detected in the Mekong River Basin of Cambodia and Vietnam, and these freshwater small-sized fish species, including juveniles of commercially important fish species, contribute more than 70% to total freshwater capture fisheries production.

The government of Cambodia put a ban on snakehead farming in September 2004 by the Announcement No. 4004 kor.sor.ko.sor.chor.nor. The reason for this was the potential negative impacts on wild fish populations from wasteful snakehead seed collection and on other fish species diversity, particularly the small-sized fish used as feed for snakehead aquaculture, and also potential negative effects on poor consumer groups from decreased availability of small-sized or low-value fish due to dependency of snakehead aquaculture on small-sized or low-value fish (So et al. 2007).

After the ban on snakehead culture in Cambodia, snakeheads have illegally been imported from the neighboring countries, particularly from Vietnam, to supply high local market demands in Cambodia. Furthermore, the study showed that freshwater small-sized fish have illegally been exported to Vietnam for feeding the significantly and commercially developed snakehead aquaculture in Vietnam. The first phase study also indicated that the incentives for choosing snakehead before other fish species by tens of thousands of fish farmers are strong as it generates more than 10 times higher profits than other fish species. Therefore, the ban does not only result in positive impacts on poor consumer groups from increased availability of freshwater small-sized fish in Cambodia, but also providing negative effects on food and nutrition security and livelihood of tens of thousands of snakehead farmers who depend on this livelihood for improving household food and nutrition security and generating household income. In other words, these snakehead fish farmers have lost their important livelihoods and household income. Moreover, the ban also does not provide positive impacts on snakehead wild stocks as fishing pressure on wild snakehead using illegal and destructive fishing gears particularly electro-shockers has increased in recent years in order to supply local and external markets.

In order to remove this ban, the same announcement mentioned that successful technologies of domesticated breeding, weaning and rearing or growing-out of snakeheads using formulated diets should be developed and applicable in on-station and on-farm levels in Cambodia.

During the second phase of AquaFish CRSP (2009-2011), the wild striped snakehead *Channa striata* broodstocks were successfully developed, matured, and semi-artificially induced spawning using the hormone HCG on-station in Cambodia was accomplished (So et al. 2011). The striped snakehead *Channa striata* aged 30 days old after hatch could gradually and successful accept AquaFish CRSP Snakehead Formulated Feed developed by AquaFish CRSP project (Hien & Bengtson, 2009; 2011) in replacement of small-sized fish in the rate of 10% every three days for a period of 30 days of feeding (So et al. 2011).

The objective of the study was focused on weaning performance and grow-out of the wild *C. striata* (non-domesticated) from Cambodia compared to those of domesticated snakehead from Vietnam with assessment of survival rate and growth performance of the two types of *Channa striata* larvae or fingerling on formulated feed. Furthermore, the assessment of economic efficiency and product quality during grow-out of the both snakehead on different diets will also be conducted in a purpose to provide policy recommendations for snakehead farming in Cambodia.

To meet the objective, the experiments of weaning and grow-out of both snakeheads were conducted at Freshwater Aquaculture Research and Development Center (FARDeC). The experiments conducted were:

- Weaning on formulated feed as comparing the growth performance and survival of domesticated snakehead versus non-domesticated snakehead.
- Grow-out on three diets (pelleted feed, freshwater small-sized fish, and 50:50 mixture), as comparing the growth performance and survival of domesticated snakehead versus non-domesticated snakehead.
- Sensory analysis of snakehead products fed different diets

RESULTS

Experiment 1: Weaning performance of domesticated versus non-domesticated snakehead C. striata using formulated feed.

Introduction. Snakehead fish have been domesticated for almost two decades in Vietnam (So, 2009). In the past two decades, aquaculture of this domesticated snakehead fish has commonly been practiced by using freshwater and marine small-sized fish as directed feed. Farming snakehead is prohibited in Cambodia due to its dependence on small-sized fish in the diet and seed from the wild stock, while domestication of snakehead in the hatchery is just recently new. To address the key issues on using freshwater small-sized fish, Tran Thi Thu Hien and her colleagues at Can Tho University in Vietnam and University of Rhode Island, USA (Tran Thi Thu Hien and Bengtson, 2009) had successfully developed weaning methods and cost-effective and high-performing compounded feeds under laboratory and on-farm trial conditions that would allow less reliance on FSF and would have lower environmental impacts, the so-called AquaFish CRSP Snakehead Formulated Feed. Recently, aquaculture of snakehead has been shifted and wisely practiced by using the formulated or pelleted feeds in different cultured systems.

This study, therefore, was designed to wean non-domesticated snakehead *C. striata* (from wild stock through induced spawning) and domesticated snakehead using this formulated feed and weaning method to compare the growth performance and survival of the two snakehead strains.

Methods. A batch of *C. striata* larvae which was simultaneously produced from domesticated and non-domesticated snakehead brooders was used for weaning experiment at the same time using the same protocol (Hien and Bengtson 2009; 2011). After absorbing the yolk on day 3 after hatch, larvae were fed with *Moina* for 7 days till 10 day-old after hatch, and then larvae were fed with a mixture of dead *Moina* and ground freshwater small-sized fish, FSF (replacing Moina 20% per day by freshwater small-sized fish) for 7 days more till larvae were 17-day old after hatch. At 17-day old, weaning on formulated feed were started with replacement of freshwater small-sized fish 10% per day by formulated feed until FSF was completely substituted by formulated feed. Formulated feed contained 45% crude protein (Table 2.1; Figure 2.1).

There were two treatments with five replicated tanks each (Figure 2.2). Larvae were stocked in 50-L tanks with stocking density of five fish L^{-1}. The fish were fed to satiation by hand at 07:00, 10:00, 14:00 and 17:00 h. The uneaten feed and faeces were siphoned out before every feeding. Fish mortality, food consumption including water qualities, such as temperature, pH, and dissolved oxygen were recorded daily. Temperature ranged from 27.7-29 ºC, pH ranged from 7-8, DO ranged from 3-5 mg L^{-1}, NH_3 ranged from 0-0.1 mg L^{-1} and NO_2^- ranged 0 mg L^{-1}.

Larvae were weighted and measured (on wet basis) at biweekly intervals. At the end of the experiment, final body weight (FBW, mg), wet weight gain (WWG, mg), daily weight gain (DWG), specific growth rate (SGR) and feed intake (FI) including survival rate (SR) were determined. Weaning lasted 45 days. Difference between the treatments on growth and survival were determined by two sample t-test at p= 0.05 using SPSS 16.0.

<u>Data calculation</u>
SR (%) = (Numbers of fish at the end of experiment/ numbers of initial fish) x 100
WG (g) = Final body weight – Initial body weight
DWG (g fish^{-1} day^{-1}) = (Final body weight- Initial body weight)/ Experiment time
SGR (% of body weight day^{-1}) = ((ln final weight — ln initial weight)/ number of culture day) x100
FI = (Feed intake/no. fish)/No. days

Results and discussions. There was a significant difference observed between the treatments in growth performance, daily weight gain, feed intake and survival rate. Growth performance, daily weight gain, and feed intake in domesticated larvae were significantly higher ($p < 0.05$) than those in non-domesticated larvae (Table 2.2; Figure 2.3), while the survival rate was significantly lower ($p < 0.05$) in domesticated treatment (28.9%) than in the non-domesticated (35.7%) (Table 2.2). The cannibalism rate was not significant different between the treatments ($p > 0.05$; Table 2.2), while the mortality rate was significantly higher in the domesticated (24.5%) than in the non-domesticated (13%) (Table 2.2). Thus, domesticated snakehead are more adapted to formulated feed in term of growth and feed intake than non-domesticated snakehead. The survival of domesticated larvae was lower due to its higher mortality. The mortality might be caused due to satiation rate.

The survival rates were comparable to the start of weaning at 20-day old larvae (36.2%), but lower than fish weaned at 30-day old (68.9%) with replacement of small-sized fish 10% per day by formulated feed reported by (So Nam et al. 2011) and lower than on farm trial weaning (72.5-81.7%) at 6-7 g/fish initial weight reported by (Hien and Bengtson, 2011), however, it was higher than the weaning at 10-day old (15%) with 10% /day replacement reported by (Hien and Bengtson, 2009).

In this study, *C. striata* showed a high cannibalism (46% and 51% for domesticated and non-domesticated, respectively) in weaning to formulated feed. Hien et al. (2015) observed that *C. striata* is much more aggressive toward conspecifics in a tank. In fishes, cannibalism is usually associated with heterogeneous size variation, lack of food, high density, lack of refuge area, and light condition. Among these variables, size variation and unsuitable food are considered the primary causes of cannibalism (Hien and Bengtson, 2009).

Experiment 2: Grow-out performance of domesticated versus non-domesticated snakehead C. striata using pelleted feed, freshwater small-sized fish and 50:50 mixtures.

Introduction. Aquaculture of snakeheads in Cambodia is mainly dependent on freshwater small-sized fish (FSF) for sourcing key dietary nutrient inputs (So Nam et al. 2009; So Nam et al. 2005), and feeding cost is the highest cost for the fish farmers. The recent study by So Nam et al. (2009) revealed that more than 200 FSF species, with nearly 50,000 ton (accounting more than 10% of total freshwater fisheries production in Cambodia; So Nam et al. 2005) are used for aquaculture in Cambodia. Many problems are raised among many snakehead farms. The main problems are poor quality of FSF and variable nutritional composition because of inappropriate storage. Risk of disease introduction and out breaks, environmental pollution, and high feed conversion in snakehead rearing contributed more concerns. Moreover, the growing competition between human and aquaculture usage of FSF led to increasing its price to the fish famers (Le Xuan Sinh et al, 2009; So Nam et al. 2009; Rachmansyah et al. 2009; So Nam et al. 2007).

One key constraint and challenge to the culture of this species is the ban on snakehead culture by the government of Cambodia due to the lack of formulated diets (So Nam et al. 2009).

This experiment, therefore, was designed to grow non-domesticated snakehead (*C. striata*) and domesticated snakehead using pelleted feed, FSF, and 50:50 mixtures in order to compare the growth performance and survival of the both snakehead strains.

METHODS

A batch of the two types of snakehead fingerlings accepting formulated feed from the above weaning were used in grow-out experiments. The snakehead fingerlings were fed with three diets: 1) FSF; 2) pelleted feed (PF); 3) 50:50 mixture of FSF and PF (Mix). There were six treatments with 3 replicated-hapas each as follows:

- Domesticated fed freshwater small-sized fish (d-FSF)
- Nondomesticated fed freshwater small-sized fish (n-FSF)
- Domesticated fed pelleted feed (d-PF)
- Nondomesticated fed pelleted feed (n-PF)
- Domesticated fed 50:50 mixture (d-Mix)
- Nondomesticated fed 50:50 mixture (n-Mix)

The experiments were conducted in 18 hapa-nets (1.8m x 2.5 m x 1.8 m) with a stocking density of 100 fingerlings hapa^{-1}. The hapas were placed in three earthen ponds (300 m^2) with six hapas each assigned three replicated hapas for domesticated fingerling and three replicated hapas for non-domesticated (Figure 2.5). In pond one, snakehead fingerlings (12-13g fish^{-1}) were fed ground freshwater small-sized fish only (control); in pond two, snakehead (12-13g fish^{-1}) were fed commercial-snakehead pelleted feed (Super floating AquaFeed containing 40% crude protein) only ; and in pond three, snakehead (12-13g fish^{-1}) were fed 50:50 mixture of freshwater small-sized fish and the pelleted feed. The fish were fed to satiation twice daily at 09:00 h and 16:00 h. The amount of feed consumption and fish mortality were recorded daily. Water qualities include transparency, temperature, pH, dissolved oxygen, ammonia, nitrite were monitored weekly. Fish were weighted and measured monthly (wet basis) by sampling 30 fish per hapa. The grow-out lasted for six months. At the end of experiment, survival, final body weight (FBW, g), and wet weight gain (WWG, g), daily weight gain (DWG, g fish^{-1} day^{-1}), specific growth rate (SGR, % BW day^{-1}), feed intake (FI, g fish^{-1} day^{-1}), food conversion ratio (FCR) and survival rate (SR, %) were determined. Economic efficiency and fish product quality of different diet treatments were also evaluated.

Treatment means of the above parameters were subjected to one-way analysis of variance (ANOVA) at a 5% significance level and Duncan's multiple-range test. The effects of snakehead strains, diets and their possible interactions on the growth parameters and survival were determined using two-way ANOVA at a 5% significance level. Statistical analyses were performed using the statistical package (SPSS 16.0).

Data calculation

SR (%) = (Numbers of fish at the end of experiment/ numbers of initial fish) x 100

WG (g) = Final body weight — Initial body weight

DWG (g fish^{-1} day^{-1}) = (Final body weight — Initial body weight)/ number of experimental day

SGR (% of body weight day^{-1}) = ((ln final weight — ln initial weight)/ number of culture day) x100

FI (g fish^{-1} day^{-1}) = (Feed intake/no. fish)/ number of experimental day

FCR= Feed intake/ Weight gain

Profit (KHR; Khmer Riel) = Total income — total cost

Sensory test of fillets (see below)

RESULTS AND DISCUSSION

Water quality parameters. Water quality parameters are presented in Table 2.3. The average concentrations of the different water quality parameters remained within the safe limits for snakehead growth.

Effect of snakehead strain and diet on growth performance. The data on growth performance, feed intake, food conversion, and survival are presented in Table 2.4. At the end of the experiment (six months), the growth parameters were significantly affected by strain and diet. The FBW, WG, DWG, and SGR were significantly greater in the domesticated strain than the non-domesticated in all diet treatments (Table 2.4 and 2.5). In both strains, freshwater small-sized fish treatments were significantly lower than pelleted feed and mixture treatments, while both treatments were not significant difference (Table 2.4; 2.6). The d-PF showed the highest value for FBW (366.7 ± 8.8 g), WG (353.2 ± 8.8 g) and DWG (2.0 ± 0.0 g fish^{-1} day^{-1}), followed by the d-Mix treatment (346.7 ± 8.8 g; 333.2 ± 8.8 g; and 1.9 ± 0.0 g fish^{-1} day^{-1}) respectively). The lowest value was showed in the n-FSF treatment (210.0 ± 5.8 g**;** 196.5 ± 5.8 g; and 1.1 ± 0.0 g fish^{-1} day^{-1} respectively). In non-domesticated, the n-Mix showed the highest value (255.0 ± 2.9 g; 241.5 ± 2.9 g; and 1.3 ± 0.0 g fish^{-1} day^{-1} respectively), followed by the n-PF treatment (233.3±3.3 g; 219.8±3.3 g; and 1.2 ± 0.0 g fish^{-1} day^{-1} respectively) (Table 2.4). The highest SGR value was obtained in the d-PF and d-Mix (1.8 ± 0.0 % day^{-1}; 1.8 ± 0.0 % day^{-1} respectively); the lowest value in the n-FSF (1.5 ± 0.0 % day^{-1}); and intermediate in the n-PF, n-Mix, and d-FSF (1.6 ± 0.0% day^{-1}; 1.6 ± 0.0 % day^{-1}; and 1.7 ± 0.0 % day^{-1} respectively) (Table 2.4). Two-way ANOVA showed a significant interaction ($P < 0.05$) between strain and diet in FBW and WG.
In this study, the final body weight of the snakehead stains in the three diets showed a trend of linear increase with time (Figure 2.4).

Growth performance was significantly affected by strain and diet and their interaction. In general domesticated strain had significantly higher individual FBW, WG, DWG, and SGR than the existing non-domesticated strain. Pelleted feed and mixture treatments had significantly higher FBW, WG, DWG, and SGR than freshwater small-sized fish treatment. The results obtained in this study show FBWs and DWGs were lower than a range 391-403 g; 2.67-2.75 g fish^{-1} day^{-1} respectively for 12-13 g snakehead stocked in hapas using freshwater small-sized fish versus formulated feed respectively reported by Hien and Bengtson (2011), and lower than 562 g; 3.05 g fish^{-1} day^{-1} respectively for 2.5 g snakehead cultured in pond using commercial pellet feed at density 100 fingerlings m^{-2} for six months in demonstration farms in Vietnam reported by Hien and Bengtson (2011). However, FBWs of this study were higher than a range 136-199 g for snakehead stocked in hapas for four months in Dong Thap reported by Hien and Bengtson (2011). So Nam et al. (2011) reported FBW and DWG ranged from 313.5-467.9 g; 1.0-1.5 g fish^{-1} day^{-1} respectively for non-domesticated snakehead cultured on station in hapas fed formulated feed and freshwater small-sized fish respectively for 10 months.

Effect of snakehead strain and diet on feed intake, feed conversion, and survival. Feed intake (FI) and feed conversion ratio and production differed significantly among the six treatments. The highest FCR value was observed in the n- FSF (4.2 ± 0.1), followed by the d-FSF (3.7 ± 0.0) treatment. The best (lowest) FCR was observed in the d-PF (1.5 ± 0.0), followed by the n-PF (1.7 ± 0.1). The n-Mix and the d-Mix showed intermediate values (Table 2.4). The highest FI value was observed in the d-FSF (6.0 ± 0.1 g fish^{-1} day^{-1}), followed by the n-FSF (4.6 ± 0.2 g fish^{-1} day^{-1}) and the d-Mix (4.5 ± 0.1 g fish^{-1} day^{-1})

treatments; both were comparable. The lowest FI value was observed in the n-PF (2.1 ± 0.1 g fish^{-1} day^{-1}). The n-Mix (3.8 ± 0.1 g fish^{-1} day^{-1}) and the d-PF (3.1 ± 0.1 g fish^{-1} day^{-1}) showed intermediate values (Table 2.4). Feed intake and feed conversion ratio pooled across diets were significantly higher in freshwater small-sized fish feeding (Table 2.6). However, data pooled across strains showed the FI and FCR to have no significant difference (Table 2.5). Survival was significantly different among treatments (Table 2.4). However, data pooled across stains and diets (Table 2.5 and 2.6) showed no significant differences. Survival ranged from 61.3 % to 77.5 %. Two-way ANOVA showed a significant interaction between strain and diet in FI, FCR, survival rate, and production.

In aquaculture, the cost of feed is a major component of the operating cost of fish farms. In Cambodia, snakehead feed cost accounts for more than 70% of the total expenses (So et al. 2005). Therefore, any improvement in FCR would have a positive impact in reducing the production cost. In this experiment, the d-PF and n-PF showed significantly lower FCR values than other treatments. The FCR range of 1.5-4.2 obtained in this study was comparable with the range of 1.4 - 4.4 reported by Hien and Bengtson (2011), and the range of 1.7 – 4.2 reported by So Nam et al. (2011) for formulated feed and freshwater small-sized fish feeding, respectively. In the present study, FCR was significantly affected by diet (Table 2.6), but not significantly affected by fish strain. Freshwater small-sized fish feeding showed higher FCR than other treatments, while lower FCR was in pelleted feed treatment. In this study, the survival rate was intermediate in all treatments (61.3% - 77.5%) and was not influenced by strain and diet, but their interaction showed significant difference among the treatments. The survival rate of the study was comparable with the range of 54.6% - 79.7% reported by Hien and Bengtson (2011), and the range of 56% - 60% reported by So Nam et al. (2011).

Economics. The economics of experimental snakehead was presented in Table 2.7 and 2.8. In this experiment, since feed cost was accounted for more than 70% of the total expenses, we focused only feed cost and income from selling snakehead on farm get price in the current market to make economic analysis. The n-FSF and n-Mix showed lost profit (-0.5 ± 0.1 x1000 KHR/kg fish produced and -0.8 ± 0.3 x1000 KHR/kg fish respectively). The highest profit value showed in the d-PF treatment (1.3 ± 0.2 x1000 KHR/kg fish respectively), followed by the d-Mix and n-PF (0.9 ± 0.4 x1000 KHR/kg fish respectively; 0.9 ± 0.3 respectively x1000 KHR/kg fish respectively).

Fish product quality

Method. At the end of the experiment, all fish were killed, filleted, and washed, and then they were steamed for three minutes. First, these fish were used to determine the difference in the quality of fish fillet between the control and experimental groups by triangle test (two controls and one sample) with three replacements per test (Hien and Bengtson, 2011). And the control sample was the snakehead which was bought at the local market. There were six samples named n-FSF, n-PF, n-Mix, d-FSF, d-PF, and d-Mix.

If less than six out of nine detected the odd sample correctly, we determined that there was no significant difference and therefore no need to conduct a sensory test. A multiple range-test was run if there were any difference in any sensory attributes for texture or taste even if they were minor—called a "descriptive test". On the other hand, if seven out of nine people detected the odd sample correctly, there was a significant difference at $p<0.01$ or six out of nine $p<0.05$. In this case, it was necessary to do a comprehensive multiple range-tests on appearance, texture, and taste. Tests are hedonic and score on an intensity scale (one to-9 points) on appearance such as liking (1, least like—5, o.k.—9, like very much, whiteness (1, dark—5, medium—9, very white), and structural integrity (uniformity: 1, very irregular—5, medium—9, very uniform); taste, for example liking (1, least like—5, o.k.—9, like very much); snakehead-like taste (1, very little—5, o.k.—9, very much); presence of objectionable taste (yes or no) and presence of objectionable odor (yes or no); texture, for instance, liking (1, least like—5, o.k.—9, like very much); firmness (1, very soft—5, medium—9, very firm); moistness (1, very dry—5, medium—9, very moist); chewiness (1, mushy—5, medium—9, very chewy); and flakiness (1, least or rubbery—5, medium—9, very flaky). Mean values of results in different treatments were compared by Duncan's multiple-range test using SPSS 16.0 software. Treatment effects were considered with the significance level at $p< 0.05$.

RESULTS

Sensory analysis. The sensory analysis was presented in Table 2.9 and 2.10. In appearance, both fish fed freshwater small-sized fish, pelleted feed and mixture feed received scores of approximately six to seven, meaning that the fillets were relatively likeable for liking; rather white for whiteness and relatively uniform for structural integrity. In taste, the fish fillets had snakehead-like taste without the presence of objectionable taste or odor. In texture examination, for liking score was from six to seven meaning fairly or relatively like. For firmness, the scores were around six, medium or rather firm fish fillet. The fillet moistness was medium (no dry and not moist). The fillet chewiness and flakiness was judged to medium (not mushy and not chewy; not rubbery and not flaky).

The result showed that there were no significant differences between samples in triangle tests (less than six out of nine people detected the odd sample correctly). These samples were then subjected to descriptive multiple tests, with the result that the quality of fish fillet samples among the treatments did not significantly differ.

In summary, snakehead fillet quality was relatively like and did not significantly differ among samples in triangle tests. In descriptive multiple tests, there were also no significant differences among the samples. So, the diets and snakehead strains did not effect on the quality of fish fillet for fish in these experiment.

CONCLUSION

The study concludes that both Vietnam hatchery snakehead (domesticated) and Cambodia indigenous wild snakehead (non-domesticated) can accept formulated feed, with similar product quality. However, Vietnam hatchery snakehead show higher growth rate and profit than Cambodia wild capture snakehead because Vietnam hatchery snakehead has been undergone domestication and selection breeding for more than 20 years. Considering economic efficiency, replacing freshwater small-sized or low-value fish by formulated feed up to 100% is possible for both Vietnamese domesticated snakehead and Cambodian non-domesticated snakehead, however, the domesticated snakehead (about US$0.35/kg fish) shows higher profit than Cambodian non-domesticated snakehead (US$ 0.25/kg fish).

Using formulated or pelleted feed for snakehead culture provides significantly better growth performance, FCR and higher profit than using freshwater small-sized fish and mixture diets.

In regards product quality, formulated or pelleted feed does not significantly affect the fillet quality of both Vietnamese and Cambodian cultured snakehead compared to a diet of freshwater small-sized low value fish or 50:50 mixtures of small-sized fish and pelleted feed. In a quality test, diets and fish strains do not affected the fillet quality among the samples.

RECOMMENDATIONS

The following recommendations should be carefully considered for policy and action plan development in order to lift the ban on snakehead and achieve sustainable development snakehead aquaculture in Cambodia:

- The availability of hatchery broodstock has" very important implications" for protecting the small sized fishes that are usually fed to snakeheads

- Collecting striped snakeheads from different natural water bodies across the country to develop sufficient numbers of broodstock at hatcheries for research into breeding and weaning techniques to produce high-quality seed
- Characterizing biologically striped snakeheads from different populations in the Tonle Sap Lake, the upper and lower stretches of the Mekong and Bassac rivers and their associated floodplains to determine favorable traits for aquaculture development.
- Assessing genetic diversity and populations in different locations to maintain the diversity of wild stocks, conserve the species and enhance broodstock diversity when conducting domestication and breeding programs
- Substituting small-sized fish with formulated feed would help lift Cambodia's ban on snakehead farming which has now been in force for 10 years
- Optimizing survival and growth rate of Cambodia indigenous snakehead through development of F_2 and F_3 generation broodstock and genetic selection of wild capture snakehead collected from different natural water bodies in Cambodia
- Developing practical formulated diets for snakehead broodstock, fry and fingerlings to replace small-sized fish from capture fisheries
- Providing extension services to farmers on techniques for snakehead breeding, weaning and grow-out using formulated diets
- Encouraging the government, business and development partners to invest in the value chain of snakehead aquaculture development, especially the private sector to formulate and improve commercially manufactured feed that is better integrated into local economy with fewer imported ingredients and lower prices

QUANTIFIED ANTICIPATED BENEFITS

This research provides information on domesticated breeding, weaning and growing out of snakehead fish, especially development of Cambodia's snakehead aquaculture technologies, in order to lift the ban on snakehead culture in Cambodia. The following are quantifiable anticipated benefits:

- Scientists, researchers, government fisheries officers/managers and policy makers, extension workers, NGO staffs, private sector and university lecturers and students working on the issues of snakehead aquaculture in Cambodia as well as in other Mekong riparian countries were better informed about research methods and findings, and have better recommended policies and strategies for sustainable snakehead aquaculture
- Three undergraduate students were supported and trained by this investigation through their B.Sc. thesis researches
- Benefits to the US include improved knowledge and technologies on domestication of freshwater fish species for aquaculture and this aquaculture is considered as a climate change adaptation measure

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TABLES AND FIGURES

Table 2.1 Formulated feed formulation (about 45% CP) for weaning.

Main ingredients	(g)
Fish meal	570
Soy bean meal	140
Rice bran	100
Cassava meal	130
Vitamin C	2
Premix mineral-Vitamin	15
Fish oil	25
Phytase	0.2
Binder	17.8
Total	1000

Table 2.2 Survival rate (%), Cannibalism rate, feed intake (%), body weight (mg.fish^{-1}), and daily weight gain (mg.day^{-1}) of non-domesticated vs. domesticated *Channa striata* weaned to formulated feed (FF) for 45 days.

Parameters[1,2]	Treatments	
	Nondomesticated	Domesticated
Stocking		
Density (larvae l^{-1})	5	5
Total larvae (larvae tank^{-1})	250	250
Initial weight (mg fish^{-1})	2.1	2.1
Initial length (mm fish^{-1})	12	12
Harvest		
Total fish (fish tank^{-1})	89	72
Final body weight (mg fish^{-1})	145.5^a ± 5.2	170.2^b ± 2.6
Weight gain (mg fish^{-1})	143.4^a ± 5.2	168.1^b ± 2.6
Daily weight gain (mg fish^{-1} day^{-1})	3.2^a ± 0.1	3.7^b ± 0.1
Length (mm fish^{-1})	23.0^a ± 0.6	24.5^a ± 0.7
SGR (% day^{-1})	9.4^a ±0.1	9.8^b ± 0.03
Feed intake (mg fish^{-1}day^{-1})	84.9^a ± 3.7	106.6^b ± 8.3
Survival (%)	35.7^a ± 1.6	28.9^b ± 1.9
Mortality (%)	13^a ± 2.5	24.5^b ± 2.3
Cannibalism (%)	51.3^a ± 3.4	46.6^a ± 2.8

[1]In each row, data having different superscripts are significantly different ($p < 0.05$).
[2]Data are means ± SE. (n=5).

Table 2.3 Water quality parameters in ponds fed freshwater small-sized fish, pelleted feed and mixture.

Ponds	Temperature (ºC)	pH	DO (ppm)	Transparency (cm)	NH_3 (mg L^{-1})	NO^-_2 (mg L^{-1})
Freshwater small-sized fish	29-34	7-8	3-5	25-30	0.003-0.002	0.01-0.05
Pelleted feed	29-35	8-9	4-6	18-25	0.02-0.09	0.01-0.05
Mixture	29-35	8-9	4-6	20-30	0.02-0.08	0.01-0.08

Table 2.4 Final body weight (FBW), weight gain (WG), daily weight gain (DWG), specific growth rate (SGR), feed intake (FI), food conversion ratio (FCR) and survival (SR) of two strains of snakehead fed three diets for 6 months.

Parameters[1,2]	**Treatments**					
	n-FSF	**n-PF**	**n-Mix**	**d-FSF**	**d-PF**	**d-Mix**
Stocking						
Density (fish $hapa^{-1}$)	100	100	100	100	100	100
Initial weight (g $fish^{-1}$)	13.5 ± 0.7	13.5 ± 0.7	13.5 ± 0.7	13.5 ± 0.7	13.5 ± 0.7	13.5 ± 0.7
Harvest						
FBW(g $fish^{-1}$)	210.0 ± 5.8^{c}	233.3 ± 3.3^{d}	255.0 ± 2.9^{d}	305.0 ± 4.1^{a}	366.7 ± 8.8^{b}	346.7 ± 8.8^{b}
WG (g $fish^{-1}$)	196.5 ± 5.8^{c}	219.8 ± 3.3^{d}	241.5 ± 2.9^{d}	291.5 ± 4.1^{a}	353.2 ± 8.8^{b}	333.2 ± 8.8^{b}
DWG (g $fish^{-1}day^{-1}$)	1.1 ± 0.0^{c}	1.2 ± 0.0^{d}	1.3 ± 0.0^{d}	1.6 ± 0.0^{a}	2.0 ± 0.0^{b}	1.9 ± 0.0^{b}
SGR (% day^{-1})	1.5 ± 0.0^{c}	1.6 ± 0.0^{d}	1.6 ± 0.0^{d}	1.7 ± 0.0^{a}	1.8 ± 0.0^{b}	1.8 ± 0.0^{b}
FI (g $fish^{-1}$ day^{-1})	4.6 ± 0.2^{cd}	2.1 ± 0.1^{e}	3.8 ± 0.1^{f}	6.0 ± 0.1^{a}	3.1 ± 0.1^{b}	4.5 ± 0.1^{c}
FCR	4.2 ± 0.1^{d}	1.7 ± 0.1^{e}	2.8 ± 0.1^{f}	3.7 ± 0.0^{a}	1.5 ± 0.0^{b}	2.4 ± 0.1^{c}
SR (%)	77.5 ± 3.9^{b}	68.5 ± 5.5^{c}	61.3 ± 0.9^{d}	64.9 ± 2.2^{ac}	75.7 ± 4.1^{b}	64.9 ± 1.6^{ac}
Production (Kg $hapa^{-1}$)	15.2 ± 0.6^{c}	15.0 ± 1.2^{c}	14.8 ± 0.3^{c}	18.9 ± 0.4^{a}	26.7 ± 1.0^{b}	21.6 ± 1.1^{a}

[1]In each row, data having different superscripts are significantly different ($p < 0.05$).
[2]Data are means ± SE. (n=3)
n, nondomesticated; d, domesticated; FSF, freshwater small-sized fish; PF, Pelleted feed; Mix, 50% mixture of FSF and PF.

Table 2.5 Effect of snakehead strain on growth, Feed Intake, FCR and survival rate.

Parameter[1,2]	**Nondomesticated**	**Domesticated**
FBW(g $fish^{-1}$)	232.8 ± 6.8^{a}	342.2 ± 8.9^{b}
WG (g $fish^{-1}$)	219.3 ± 6.8^{a}	328.7 ± 8.9^{b}
DWG (g $fish^{-1}day^{-1}$)	1.2 ± 0.04^{a}	1.8 ± 0.05^{b}
SGR (% day^{-1})	1.6 ± 0.01^{a}	1.8 ± 0.02^{b}
FI (g $fish^{-1}$ day^{-1})	3.5 ± 0.4^{a}	4.6 ± 0.4^{b}
FCR	2.9 ± 0.4^{a}	2.6 ± 0.3^{a}
SR (%)	69.1 ± 3.1^{a}	68.5 ± 2.3^{a}
Production(kg $hapa^{-1}$)	15 ± 0.4^{a}	22 ± 1.2^{b}

[1]In each row, data having different superscripts are significantly different ($p < 0.05$).
[2]Data are means ± SE. (n=9).
FBW, final body weight; WG, weight gain; DWG, daily weight gain; SGR, specific growth rate; FI, feed intake; FCR, food conversion ratio; SR, survival rate.

Table 2.6 Effect of diet on growth, Feed Intake, FCR and survival rate.

Parameter[1,2]	FSF	PF	Mix
FBW(g fish^{-1})	261.7 ± 23.6^{b}	300.0 ± 30.1^{a}	300.8 ± 20.9^{a}
WG (g fish^{-1})	248.2 ± 23.6^{b}	286.5 ± 30.1^{a}	287.3 ± 20.9^{a}
DWG (g fish^{-1}day^{-1})	1.4 ± 0.1^{b}	1.6 ± 0.2^{a}	1.6 ± 0.1^{a}
SGR (% day^{-1})	1.6 ± 0.05^{b}	1.7 ± 0.05^{a}	1.7 ± 0.05^{a}
FI (g fish^{-1} day^{-1})	5.4 ± 0.3^{a}	2.6 ± 0.3^{b}	4.2 ± 0.2^{c}
FCR	4.0 ± 0.2^{a}	1.7 ± 0.04^{b}	2.7 ± 0.1^{c}
SR (%)	71.2 ± 3.4^{a}	72.1 ± 3.5^{a}	63.1 ± 1.1^{a}
Production (kg hapa^{-1})	17.3±0.98^{a}	20.8±2.7^{a}	18.2±1.6^{a}

[1]In each row, data having different superscripts are significantly different ($p < 0.05$).
[2]Data are means ± SE. (n=6).
FBW, final body weight; WG, weight gain; DWG, daily weight gain; SGR, specific growth rate; FI, feed intake; FCR, food conversion ratio; SR, survival rate; FSF, freshwater small-sized fish; PF, pelleted feed; Mix, Mixture of freshwater small-sized fish and pelleted feed.

Table 2.7 Economics of experimental snakehead culture per hapa.

Treatments	Total cost (feed) (thousand KHR/hapa)	Total income (thousand KHR/hapa)	Profit (thousand KHR/hapa)
n-FSF	129.0 ± 4.7^{a}	121.6 ± 5.1^{a}	-7.4 ± 1.8^{a}
n-PF	106.1 ± 4.2^{b}	120.4 ± 9.5^{a}	14.3 ± 5.4^{b}
n-Mix	130.1 ± 1.7^{a}	118.4 ± 2.3^{a}	-11.7 ± 3.9^{c}
d-FSF	140.4 ± 2.2^{c}	151.2 ± 3.0^{c}	10.8 ± 0.9^{d}
d-PF	178.6 ± 9.4^{d}	213.3 ± 7.7^{d}	34.7 ± 3.9^{e}
d-Mix	162.3 ± 1.4^{e}	181.1 ± 3.7^{e}	19.1 ± 2.5^{f}

Table 2.8 Economics of experimental snakehead culture per kg fish produced

Treatments	Total cost (feed) (thousand KHR/Kg fish)	Total income (thousand KHR/Kg fish)	Profit (thousand KHR/Kg fish)
n-FSF	8.5±0.1^{a}	8.0±0.00	-0.5 ±0.1^{a}
n-PF	7.1±0.3^{b}	8.0± 0.00	0.9± 0.3^{b}
n-Mix	8.8 ±0.3^{a}	8.0 ±0.00	-0.8 ±0.3^{c}
d-FSF	7.4±0.03^{c}	8.0± 0.00	0.6 ±0.03^{d}
d-PF	6.7 ±0.2^{d}	8.0± 0.00	1.3 ± 0.2^{e}
d-Mix	7.5±0.4^{e}	8.0± 0.00	0.9 ± 0.4^{f}

Table 2.9 Triangle test for difference (number from a 9-person sample who detected the odd sample correctly, data are mean ± SD.

n-FSF	n-PF	n-Mix	d-FSF	d-PF	d-Mix
3.0 ± 1.0	2.7 ± 0.6	3.3 ± 1.2	2.3 ± 0.6	3.7 ± 1.5	4.0 ± 1.0

Table 2.10 Channa striata sensory analyses, data are mean ± SD.

Content	Scores					
	n-FSF	n-PF	n-Mix	d-FSF	d-PF	d-Mix
Appearance						
Liking	6.1 ± 0.8	6.4 ± 0.9	7.0 ± 0.9	6.6 ± 1.3	6.7 ± 1.3	6.9 ± 0.9
Whiteness	6.5 ± 1.2	6.9 ± 0.8	6.5 ± 1.0	6.6 ± 0.9	6.5 ± 1.2	6.3 ± 1.0
Structural integrity	6.4 ± 2.1	7.0 ± 1.3	6.9 ± 1.1	6.5 ± 1.7	6.3 ± 1.9	6.6 ± 2.1
Taste						
Liking	6.6 ± 1.6	7.4 ± 1.0	6.9 ± 0.8	7.0 ± 0.8	7.0 ± 1.3	7.1 ± 0.8
Snakehead-like taste	8.0 ± 0.9	7.6 ± 0.9	7.5 ± 0.9	7.5 ± 0.8	7.7 ± 0.9	7.6 ± 1.0
Presence of objectionable taste	No	No	No	No	No	No
Presence of objectionable odor	No	No	No	No	No	No
Texture						
Liking	5.9 ± 1.5	7.0 ± 1.1	6.8 ± 1.0	7.0 ± 1.1	6.9 ± 1.1	6.9 ± 1.3
Firmness	6.3 ± 1.0	6.9 ± 1.1	6.0 ± 1.1	6.1 ± 1.2	6.1 ± 1.1	6.5 ± 0.8
Moistness	4.9 ± 1.0	5.1 ± 1.2	5.3 ± 1.3	4.8 ± 1.0	5.7 ±1.4	4.8 ± 1.3
Chewiness	5.3 ± 1.4	5.1 ± 0.8	6.0 ± 1.3	4.8 ± 0.7	5.4 ± 1.1	5.0 ± 1.2
Flakiness	4.8 ± 1.0	4.9 ± 2.0	5.0 ± 2.3	4.6 ± 1.1	5.9 ± 1.1	4.9 ± 1.2

Figure 2.1. Formulated feed preparation for weaning experiment.

Figure 2.2. Weaning experiement replicated tanks.

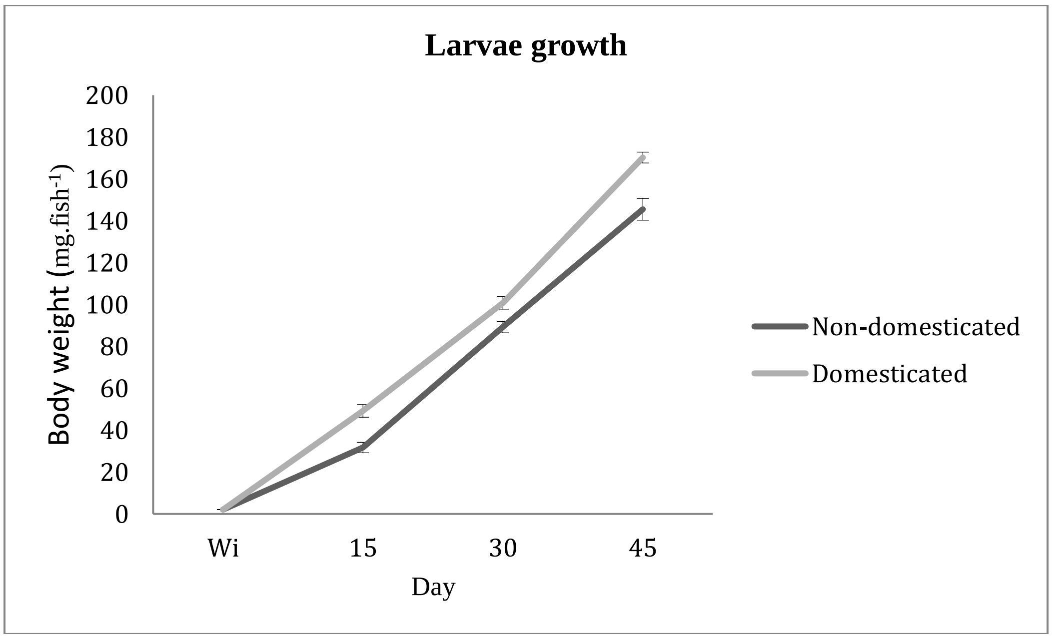

Figure 2.3 The growth performance of nondomesticated vs. domesticated *C. striata* weaned to formulated feed (Wi = Initial weight).

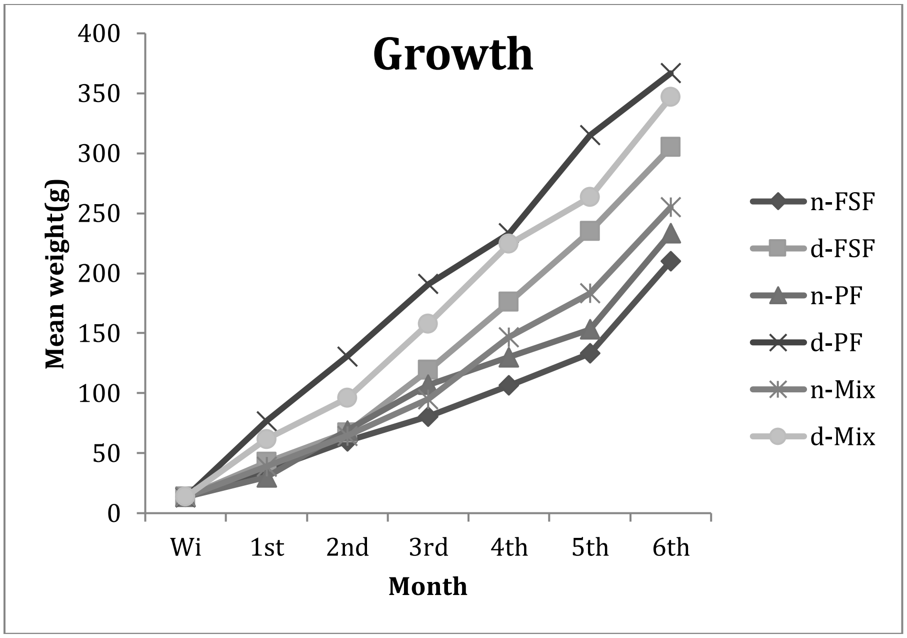

Figure 2.4 Growth graph for domesticated and non-domesticated strains of snakehead fed three diets: nondomesticated fed freshwater small-sized fish (n-FSF), Pelleted feed (n-PF), 50:50 mixture of freshwater small-sized fish and formulated feed (n-Mix); and domesticated fed freshwater small-sized fish (d-FSF), formulated feed (d-PF), 50:50 mixture of freshwater small-sized fish and formulated feed (d-Mix).

Figure 2.5. Grow-out experiment (left: freshwater small-sized fish fed pond; middle: pelleted feed-fed pond; right: mixture-fed pond).

Figure 2.6 Snakehead fish sampling at harvest of six month grow-out (Fish: upper: domesticated snakehead; lower: non-domesticated snakehead; from left to right: Pelleted feed fed-fish, 50:50 mixture fed fish and freshwater small-sized fish fed fish).

Figure 2.7 Snakehead fillet quality test (sensory test).

APPENDIX
Questionnaires
Snakehead Fish *Channa striata* Sensory Analysis

Fish________________; Diet__________________ **Name_________________**

Content	Scores
I. Appearance	• Liking 1☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6☐ 7☐ 8☐ 9☐ (1, least like--- 5, o.k.--- 9, like very much)
	• Whiteness 1☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6☐ 7☐ 8☐ 9☐ (1, dark--- 5, medium--- 9, very white)
	• Structural integrity 1☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6☐ 7☐ 8☐ 9☐ (Uniformity: 1, very irregular--- 5, medium--- 9, very uniform)
II. Taste	• Liking 1☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6☐ 7☐ 8☐ 9☐ (1, least like--- 5, o.k.--- 9, like very much)
	• Snakehead-like taste 1☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6☐ 7☐ 8☐ 9☐ (1, very little--- 5, o.k.--- 9, very much)
	• Presence of objectionable taste Yes ☐ No☐
	• Presence of objectionable odor Yes ☐ No ☐
III. Texture	• Liking 1☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6☐ 7☐ 8☐ 9☐ (1, least like--- 5, o.k.--- 9, like very much)
	• Firmness 1☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6☐ 7☐ 8☐ 9☐ (1, very soft--- 5, medium--- 9, very firm)
	• Moistness 1☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6☐ 7☐ 8☐ 9☐ (1, very dry--- 5, medium--- 9, very moist)
	• Chewiness 1☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6☐ 7☐ 8☐ 9☐ (1, mushy---5, medium--- 9, very chewy)
	• Flakiness 1☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6☐ 7☐ 8☐ 9☐ (1, least or rubbery--- 5, medium--- 9, very flaky)