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Effects of season, geographical origin, and species on the fillet quality of Asian carp harvested from the Illinois River

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Running title : Factors affecting Asian carp quality

Abstract: Exportation of Asian carp from the Illinois River to China is an emerging business with ecological and economic benefits. The current market environment supports the shipment of frozen Asian carp to China; however, lack of standardization in harvesting, hauling, and processing techniques present challenges for product quality. The objective of this study was to evaluate seasonal, spatial, and species effects on fillet quality of Asian carp harvested from the Illinois River. As such, Bighead and Silver Carp were harvested on two occasions (summer and fall) from two geographically distinct reaches (Alton and Peoria) of the Illinois River. Lower ($P<0.05$) fillet pH, Torrymeter freshness values, and higher aldehyde concentrations were observed in fillet coming from fish harvested in summer compared to those harvested in fall. Asian carp caught in the Alton Reach had lower ($P<0.05$) fillet pH, post-processing freshness values, and higher aldehyde concentrations than those from the Peoria Reach. Summer harvested fish had higher ($P<0.05$) whiteness values than fall harvested fish. Lower ($P<0.05$) pH, freshness values, and increased peroxide concentrations were observed in Bighead Carp relative to Silver Carp fillets.This is the first report of color and Torrymeter freshness values for Silver and Bighead Carp. This can establish a reference for future research in commercial evaluation of flesh quality for these two species.Indicators of shelf life suggest improved product quality for a frozen fish export market can be achieved by concentrating harvest on Silver Carp in the Peoria Reach during the fall season.

Key words: Asian carp, fillet quality, color, freshness, peroxide, aldehyde

INTRODUCTION

In the Illinois River, two nonnative fish species, Bighead Carp (*Hypophthalmichthys nobilis*) and Silver Carp (*H. molitrix*), known collectively as 'Asian carp', are highly invasive. While mostly undesirable in the United States, Asian carp are in high demand internationally asfoodfish. Bighead and Silver Carp, along with Grass Carp (*Ctenopharyngodon idella*) and Black Carp (*Mylopharyngodon piceus*) are considered the four most economically and culturally important food fish in China (Duan et al., 2009). However, habitat destruction, overfishing, and pollution have drastically reduced native populations throughout Asia, forcing consumers to rely on aquaculture to meet demand (Duan et al., 2009). With concerns of pollution and very little regulation placed on Chinese aquaculture (Zhen-Yu et al. 2012), enterprises in both the United States and China are presently developing Chinese markets for frozen Asian carp harvested from the Illinois and other water systems in the United States. As a result, processors along the Illinois River have begun exporting whole frozen fish to China where they are marketed to the burgeoning middle and upper class markets. Given the potential ecological and economic benefits of this industry, it is important to optimize harvest practices to provide the highest quality product.

Asian carp from the Illinois River are presently harvested throughout the year, except during times of river freezing or flooding. Anecdotal observations by fisherman and processors of flesh quality and shelf life of Asian carp harvested from the Illinois River suggest poorer flesh quality from summer harvested fish and improved flesh quality from fish harvested in the fall. Seasonal differences in temperature, dissolved oxygen levels, turbidity, food availability, photoperiod, behavior, and physiology have been demonstrated to affect quality parameters of many sport and food fish (Nettleton and Exler, 1992; Saito et al., 1999; Alasalvar et al., 2002).

Geographical origin of harvested fish may also have an effect on Asian carp flesh quality. Like most rivers in the United States, the Illinois River has been subject to a high degree of habitat modification (Havera and Bellrose, 1985; Sparks, 1992; Nelson et al., 1994; Warner, 1998). The Peoria Reach is the point of change from physically different habitats of the upper to lower river. The upper reaches of the Illinois River are extensively dammed (Thompson, 1989; Sparks et al., 1990), and these activities have severely impacted flow regimes, widened the river, and reduced backwater habitat (Starrett, 1972). Increased agricultural use in the lower portions of the Illinois River has resulted in large scale draining of many backwater areas for farmland and the channelization of main river habitats (Nelson et al., 1994). Alton Reach has experienced the greatest loss of floodplain to levees and also receives the greatest sediment load because it is the furthest downstream reach (Mills et al., 1966). Much like seasonal differences, differences in habitat are likely to have an effect on final fillet quality due to a long list of biotic and abiotic factors including temperature regimes, dissolved oxygen levels, and food availability. Commercial fishermen and processors have also indicated that Silver Carp do not “hold up as well” as Bighead Carp during harvest, processing, and shipping (personal communication). Accordingly, the objectives of this study were to assess seasonal, spatial, and species effects on Asian carp fillet quality by evaluating Silver and Bighead Carp harvested from different geographic regions (reaches) along the Illinois River in the summer and fall seasons.

MATERIALS AND METHODS

Sample Collection

To determine the seasonal and spatial effects on fillet quality and composition, Silver and Bighead Carp, having average (mean ± SE) lengths of 585 ± 14 mm and 751 ± 28 mm, respectively, and weights of 2252 ± 152 g and 4358 ± 286 g, respectively, were sampled in July 2012 (summer) and October 2012 (fall) from the Alton and Peoria reaches of the Illinois River. At each sampling, twenty fish, 10 Silver and 10 Bighead Carp, were collected from commercial fishermen following harvest with trammel nets, and were of typical commercial harvest size. All fish used in this research were harvested within 20 minutes after initial net set, and samples were collected as commercial fishermen pulled nets. Harvest location as well as surface water temperature was recorded at the net set site.

Fish analyses

Seasonal and spatial effects were evaluated on five fresh fish of each species. The fish were immediately pithed upon capture, a skin section of approximately 5 cm by 5 cmwas removed directly ventral to the dorsal fin, and red meat was cut away to access the white muscle fillet. Fillet pH was determined by gently inserting the electrode of a HANNA HI 99163 digital meat pH and temperature probe (Hanna instruments, Smithfield, Rhode Island) into the fillet. Fillet color was quantified using a Hunterlabminiscan EZ colormeter (Hunter Associates Laboratory Inc, Reston Virginia). The view port and sample were wiped down with paper towels and washed with deionized water to remove blood and other impurities before each color reading. Settings on the colormeter were predetermined in consultation with Hunter Associates Laboratory technical staff and were as follows: an absolute display was used to output raw colorscale values, and the Illuminant/Observer value (Ill/Obs) was set at D65/10o with the Illuminant value of D65 representing daylight with a correlated color temperature of approximately 6500K. The Hunter Lab L*a*b* color scale measures three values determined along different axes. The L* value is a value of lightness measured on a scale of 0 to 100, with a value of zero indicating a completely black reading and a value of 100 indicating a pure white reading. The a* value represents the degree of greenness or redness centered around zero, with negative values indicating greenness, zero indicating grey, and positive values indicating redness. The b* value represents the degree of blueness or yellowness centered around zero, with negative values indicating blueness, zero indicating grey, and positive values indicating yellowness. Hunterlab L*a*b* output values wereused to calculate a simplified score of perceived whiteness of fillet tissue, as described by Sathivel(2005).The equation is as follows: $\text{Whiteness} = 100 - [(100-L)^2 + a^2 + b^2]^{1/2}$

Fillet samples of approximately 5 cm x 5 cm x 3 cm thick were then collected from these fish, placed in separately labeled sample bags, and kept on ice for transportation to the laboratory. In the laboratory, fillet samples were stored at -20^{o}C until proximate analysis could be completed to determine moisture, crude protein, crude lipid, and ash content. Moisture content was determined by lyophilization (Seligman and Farber, 1971), and desiccated fillet samples were ground prior to further analytical procedures. Samples for crude protein analysis were dry combusted using a LECO model FP-528 nitrogen determinator (LECO Corp., St. Joseph, MI), and protein was calculated from percent nitrogen, in accordance with the AOAC Official Method 992.15. Crude lipid content was determined following AOCS official procedure AM 5-04 (ANKOM Technology, Macedon, NY) using an ANKOM XT10. Ash content of fillet samples was determined via combustion in a muffle furnace at 600°C following AOAC protocol number 942.05.

In addition to the fresh fish analyses, five whole fish of each species were simultaneously collected from the commercial fishermen, placed in tubs with ice, and transported to the commercial processing plant. This trip took approximately 2.5 h from sites on the Peoria Reach and 0.75 h from sites on the Alton Reach. Torrymeterfreshness values were taken using a Distell Fish Freshness Torrymeter® (Distell Inc., West Lothan, UK) both immediately after harvest and upon arrival at the processor. The Torrymeter freshness analyzer is a handheld device modeled on human perception of freshness in fish products. This device measures dielectric properties of fresh or recently thawed fish and outputs a value on a scale of 0.1 to 14, with 0.1 indicating a high degree of decay and 14 a high degree of freshness. Whole fish were frozen in a blast freezer until core temperatures reached approximately -33^{o}C following standard industrial procedures. These fish were then stored in a deep freezer maintained at -20^{o}C on the premises of the fish processing plant for 6 weeks to simulate shipping and holding conditions for export to China.

After 6 weeks of frozen storage, the fish were allowed to thaw overnightat 21^{o}C for approximately 12 hours.Fillet sections were then cut, and pH, color, and freshness values were determined on thawed fillets as previously described for fresh fillets. The content of degradation products, peroxide and aldehyde,were analyzed using Peroxysafe and Aldesafe colorimetric assay kits (Saftest, Inc., Phoenix, Arizona).All experimental protocols were approved by the Institutional Animal Care and use Committee (IACUC) of Southern Illinois University, Carbondale (Protocol number 12-029).

Statistical Analysis

Statistical analyses were performed using Statistical Analysis System software (SAS Institute Inc. 2002-2008, Software Release 9.2, Cary, NC, USA). Significant differences within the dependent variables were determined by three-way analysis of variance (ANOVA) with season, geographical origin and species as independent variables. Differences between freshness values over time (fresh, pre-process, post-thawed) were determined by one-way analysis of variance. Spearman correlation coefficients were used to assess normality, and data were transformed to attain normality. If normality could not be achieved, data was analyzed non-parametrically using Kruskall-Wallis one-way analysis of variance for each main effect. If the ANOVA was significant, pair-wise contrasts using Fisher's LSD test were performed to identify significant differences between treatments within the main effects at the alpha = 0.05 level.

RESULTS

Seasonal Effects

Water temperatures during sampling in the Alton Reach were 31^{o}C in the summer and 17^{o}C in the fall, while water temperatures in Peoria Reach were 33^{o}C in the summer and 12^{o}C in the fall. Fresh fillets of fish harvested in the summer had significantly lower internal pH ($F_{1,33}$=33.71, P<0.0001) and external pH ($F_{1,35}$ = 25.71, P< 0.0001)than those harvested in the fall (Table 1). Mean (± SE) summer internal fillet temperatures in the Alton and Peoria reaches were 23 ± 0.2^{o}C and 32 ± 1.6^{o}C, respectively ($F_{1,18}$=28.75, P =0.0043), while mean (±SE) fall internal fillet temperatures in the Alton and Peoria reaches were 13 ± 0.9^{o}C and 17 ± 0.5^{o}C, respectively ($F_{1,15}$=0.03, P =0.87).

Season had a significant effect on fresh fillet color (Table 2). Summer fish had significantly lighter fillets, reflected in both whiteness (X^2_1 = 12.9325, P = 0.0003) and $L*$(X^2_1 = 12.9325, P = 0.0003) values. Fall fish had redder fillet tissue reflected in higher $a*$ values (X^2_1 = 10.2412, P = 0.0014). No significant differences between summer and fall were detected in $b*$ values, indicating that season had no significant effect on the degree of yellow-blue. Torrymeter freshness values collected immediately after harvest indicated that fall fish were significantly ($F_{1,33}$= 17.13, P = 0.0002) fresherthan those sampled in the summer (Table 3). Proximate composition of fresh fillets was also significantly affected by season (Table 4). Summer fish had higher moisture and ash concentrations and lower protein concentration than fall fish, but there was no significant effect of season on fillet lipid content.

For fish thawed after 6 weeks offrozen storage, there was no significant effect of season on fillet pH values (Table 1). Season did have a significant effecton fillet color after storage (Table 2). Summer harvested fish had significantly lighter fillet tissue reflected in higher whiteness ($F_{1,36}$= 8.40, P = 0.0064) and $L*$ values ($F_{1,36}$ = 5.83, P = 0.0210), and fall fish had significantly ($F_{1,34}$ = 19.91, P< 0.0001) redder fillets indicated by higher $a*$ values post-thawing. Fish processed in the summer had bluer fillets, indicated by lower $b*$ values ($F_{1,34}$= 52.18, P< 0.0001). Torrymeter freshness values determined when fish reached the processing plant, andafter storage and thawing were significantly higher for fall fish(X^2_1 = 13.6515, P = 0.0002). Torrymeter freshness values were also observed to decrease significantly over time regardless of season (Table 3). Fillet peroxide concentrations from thawed fish were not significantly affected by harvest season (Table 1); however, aldehyde concentrations were higher in summer caught fish.

Reach Effects

There were significant effects of geographical origin (reach) on fresh and post-thaw fillet pH values (Table1). As shown in Table 2, no significant difference was observed in fresh fish fillet whiteness (X^2_1 = 0.1570, P = 0.6920) or $L*$ (X^2_1 = 0.0037, P = 0.9514) $b*$ values ($F_{1,29}$ = 4.10, P = 0.0521)as a result of geographical origin. Geographical origin also had no significant effect on Torrymeter freshness values taken immediately after harvest (Table 3).

Table 1. Effects of species of Asian carp (Bighead and Silver Carp), season and geographic origin (Alton and Peoria reaches of the Illinois River) of harvest on mean (± SE) fresh and post-thaw fillet pH and peroxide and aldehydecon-centrations after being frozen for 6 weeks then thawed.

	Season		Reach		Species	
	Summer	*Fall*	*Alton*	*Peoria*	*Bighead*	*Silver*
Fresh pH	6.08 ± 0.05^{a}	6.57 ± 0.06^{b}	6.26 ± 0.05^{a}	6.41 ± 0.05^{b}	6.22 ± 0.05^{a}	6.44 ± 0.05^{b}
Post-thaw pH	6.24 ± 0.02	6.29 ± 0.03	6.31 ± 0.02^{a}	6.23 ± 0.03^{b}	6.22 ± 0.03^{a}	6.32 ± 0.02^{b}
Peroxide (meq/kg)	0.029 ± 0.006	0.029 ± 0.006	0.031 ± 0.006	0.028 ± 0.006	0.038 ± 0.006^{a}	0.020 ± 0.006^{b}
Aldehyde (meq/kg)	0.119 ± 0.011^{a}	0.080 ± 0.011^{b}	0.127 ± 0.011^{a}	0.072 ± 0.012^{b}	0.114 ± 0.012	0.084 ± 0.011

^{bc}Values with different superscripts are significantly different ($P \le 0.05$) within a main effect (Season, Reach, Species).

Table 2. Effects of species of Asian carp (Bighead and Silver Carp), season and geographic origin (Alton and Peoria reaches of the Illinois River) of harvest on fillet whiteness and color values. Values are mean (± SE) for Asian carp freshly caught (Fresh) and after being frozen for 6 weeks then thawed (Post-thaw).

	Season			Reach			Species	
	Summer	*Fall*		*Alton*	*Peoria*		*Bighead*	*Silver*
Fresh:								
Whiteness	53.0 ± 1.7^{a}	41.8 ± 2.0^{b}		46.8 ± 1.7	48.0 ± 2.0		50.0± 2.0	44.8 ± 1.7
*L **	54.1 ± 1.6^{a}	43.5 ± 1.9^{b}		48.1 ± 1.6	49.5± 1.9		51.0 ± 1.9	46.6 ± 1.6
*a**	1.3 ± 1.1^{a}	7.2 ± 1.2^{b}		3.2 ± 1.1	5.3 ± 1.2		2.1 ± 1.2^{a}	6.3 ± 1.1^{b}
*b**	8.8 ± 0.6	9.8 ± 0.7		8.4 ± 0.6	10.2 ± 0.7		8.5 ± 0.7	10.1 ± 0.6
Post-thaw:								
Whiteness	56.2 ± 14^{z}	49.7 ± 1.6^{y}		55.0 ± 1.4	51.0 ± 1.6		53.3 ± 1.6	52.7 ± 1.4
*L **	58.0 ± 1.4^{z}	52.8 ± 1.5^{y}		57.1 ± 1.5	53.7 ± 1.5		55.8 ± 1.5	55.0 ± 1.4
*a**	1.9 ± 0.9^{z}	7.5 ± 1.0^{y}		3.0 ± 0.9^{z}	6.5 ± 1.0^{y}		5.0 ± 1.0	4.3 ± 0.9
*b**	11.4 ± 0.4^{z}	15.2 ± 0.4^{y}		12.7 ± 0.3^{z}	13.9 ± 0.4^{y}		13.3 ± 0.4	13.3 ± 0.3

^{ab}Values with different superscripts are significantly different ($P \le 0.05$) within a main effect (Season, Reach, Species) for Fresh fillets.

^{yz}Values with different superscripts are significantly different ($P \le 0.05$) within a main effect (Season, Reach, Species) for Post-thaw fillets.

Origin of harvest had no effect on fillet ash content, but fish caught in the PeoriaReach had significantly higher moisture, lower protein, and lower lipid fillet content (Table 4).

Geographical origin also had significant effects on the quality of fish which had been frozen for 6 weeks then thawed. Post-thaw fillet pH was higher in fish caught from the Altoncompared to those from the Peoria Reach (Table 1). As shown in Table 2, origin of harvest was observed to significantly affect fillet color after storage and thawing. While no significant reach effects were observed for post thaw fillet whiteness or L* values, fish harvested from the Peoria Reach had significantly($F_{1,34}$= 7.73, P = 0.0088) redder fillets (higher a* values). The effect of geographical origin was also significant on the degree of yellow-blueness($F_{1,34}$ = 5.79, P = 0.0217). After thawing, fish harvested from the Alton Reach had bluer fillet tissue, indicated by lower b* values (Table 2).Fish harvested from the Alton Reach were also significantly fresher(X^2_1 = 5.2981, P = 0.0213) when they reached the processing plant, but had lowerTorrymeter freshness values than Peoria fish following freezing, storage, and subsequent thawing (Table 3). Geographic origin did not significantly affect fillet peroxide concentrations; however, fish harvested from the Alton Reach had significantly higher aldehyde concentrations ($F_{1,30}$ = 14.10, P = 0.0007), suggesting the initiation of the secondary degradation process (Table 1).

Species Effects

Bighead Carp had lower fresh and post-thaw fillet pH (Table 1). There were no significant differences in fresh fillet whiteness, L*, and b* values between species; however, Silver carp had significantly redder fillets, as indicated by the higher a* values (Table 2). For frozen, stored, then thawed fish, no significant differences were observed between species in fillet color (whiteness, L*, a*, and b*) values (Table 2). Torrymeter freshness values were significantlyhigher for Silver Carp at harvest and after storage and thawing (Table 3). Peroxide concentrations in Bighead Carp fillets were significantly higher post-thaw, but no significant differences were observed for aldehyde concentrations (Table 1). There was no significant effect of species on fillet moisture or crude lipid, but Bighead Carp had significantly higher ash and lower protein content than Silver Carp (Table 4).

Table 3. Effects of species of Asian carp (Bighead and Silver Carp), season and geographic origin (Alton and Peoria reaches of the Illinois River) of harvest on Torrymeter freshness values (mean ± SE) for Asian carp freshly caught (Fresh), upon reaching the processing plant (Pre-process), and after being frozen for 6 weeks then thawed (Post-thaw).

	Season		Reach		Species	
	Summer	*Fall*	*Alton*	*Peoria*	*Bighead*	*Silver*
Fresh	12.85 ± 0.13 ^{ax}	13.75 ± 0.14 ^{by}	13.30 ± 0.13^{y}	13.30 ± 0.13 ^{x}	13.10 ± 0.13 ^{ax}	13.50 ± 0.13 ^{bx}
Pre-process	11.75 ± 0.21 ^{ay}	13.38 ± 0.24 ^{by}	13.05 ± 0.21 ^{ay}	12.08 ± 0.23 ^{by}	12.48 ± 0.22^{y}	12.65 ± 0.21^{y}
Post-thawed	3.85 ± 0.27 ^{az}	4.77 ± 0.30 ^{bz}	3.90 ± 0.27 ^{az}	4.73 ± 0.28 ^{bz}	4.10 ± 0.39^{az}	4.73 ± 0.28 ^{bz}

^{ab}Values with different superscripts are significantly different (P ≤ 0.05) within a main effect (Season, Reach, Species).
^{xyz} Values with different superscripts indicate decreased(P ≤ 0.05) fillet freshness over time from harvest.

Table 4. Proximate analysis values (mean ± SE) of fresh Asian carp (Bighead and Silver Carp) fillets, comparing season (summer and fall), geographical origin (Alton and Peoria reaches), and species (Bighead and Silver Carp).^{ab}Values with different superscripts are significantly different at *P*≤0.05.

	Season			Reach			Species	
	Summer	*Fall*		*Alton*	*Peoria*		*Bighead*	*Silver*
Moisture (g/kg)	8.18 ± 0.03 ^{a}	8.02 ± 0.04 ^{b}		8.03 ± 0.03 ^{a}	8.17 ± 0.04 ^{b}		8.14 ± 0.04	8.07 ± 0.03
Crude Protein (g/kg)	1.60 ± 0.03 ^{a}	1.74 ± 0.03 ^{b}		1.73 ± 0.03 ^{a}	1.60 ± 0.03 ^{b}		1.61 ± 0.03 ^{a}	1.73 ± 0.03^{b}
Crude Lipid (g/kg)	0.048 ± 0.006	0.055 ± 0.006		0.067 ± 0.005^{a}	0.035 ± 0.006^{b}		0.057 ± 0.006	0.045 ± 0.006
Ash (g/kg)	0.13 ± 0.003 ^{a}	0.11 ± 0.003^{b}		0.12 ± 0.003	0.12 ± 0.003		0.13 ± 0.003^{a}	0.12 ± 0.003^{b}

DISCUSSION

Since Asian carp are harvested year round from the Illinois River when fishing sites are accessible, they are subjected to a wide range of environmental conditions during capture, handling, and transport, and these conditions are likely to have varying effects on final quality of the product. In the present study, lower fillet qualitywas indicated in fish harvested in the summer compared to those harvested in the fall. Higher water temperatures, such as those observed during the summer, have been associated with increased plasma cortisol concentrations in fish following a stress event (Eissa and Wang 2013), and in Yellow Perch (*Percaflavescens*) high temperature alone has been suggested to induce a chronic stress response (Tidwell et al. 1999). Furthermore, accumulation of lactic acid in muscle tissue during capture stress, as a result of anaerobic respiration,has been shown to decrease fillet pH (Lowe et al. 1993). As such, the pH of fresh fish muscle immediately post mortem has been used to evaluate perimortem stress (Poli et al., 2005).Therefore, the lower pH values observed in summer harvested fish may be indicative of greater harvesting stress at that time of year.

Strong correlations between qualitative sensory scores and Torrymeter freshness values have been observed for many commercial fish species (Burt et al., 1976; Damoglou, 1980; Lupin et al., 1980; Barassi et al., 1981; Pivarnik et al., 1990; Lougovois et al., 2003).Torrymeter values indicated that Asian carp harvested in the fall were fresher than summer harvested fish when analyzed immediately after harvest, once they reached the processing plant, and following six weeks offrozen storage then thawing. Perimortem stress has been shown to intensify the negative effects of rigor mortis and accelerate the decomposition of fish tissue (Poli et al., 2005). This is supported by the higher aldehyde concentrations in summer harvested fish fillets, which are indicative of an increased rate of secondary degradation relative to Asian carp harvested in the fall.

Shelf life of fish is often evaluated by measuring peroxide and aldehyde concentrations in fish muscle (Richards and Hultin, 2002). During storage, lipids oxidize into byproducts that impact food fish quality (Wood et al., 2004). Early lipid breakdown can be measured by analyzing peroxide concentrations, the byproduct of primary degradation. Advanced degradation is signified by an increase in aldehyde concentrations, the byproduct of the oxidation of peroxides (German and Kinsella, 1985).Higher aldehyde concentrations in summer harvested fish suggests that these fish experienced greater perimortem stress and poorer shelf life as a result. This is consistent with the observations of Trushenski and Kohler (2007), in which pre-slaughter stress was observed to increase fillet aldehyde concentrations after short-term frozen storage in Hybrid Striped Bass (*Morone chrysops*♀ x *M. saxatilis*♂).

Consumers will often accept or reject a product based solely on its appearance, consequently color is particularly important in goods destined for human consumption (Alfnes et al., 2006). The results in the present study suggest that summer fish are more desirable in regards to color of fillet tissue. Fall harvested fish had significantly darker and redder fillet tissue (indicated by lower whiteness and L* values and higher a* values) in both fresh caught fish and those subjected to simulated shipping conditions. Blueness (reflected in b* values) of fresh fish was not significantly affected by season of harvest, but summer fish had significantly bluer fillets after processing, storage and thawing, which may be preferred by consumers, as yellowing of tissue during storage has been associated with reduced quality and consumer desirability (Alfnes et al., 2006). This is contrary, however, to the freshness and degradation analyses, which indicated that fall fish were fresher and degraded slower compared to fish harvested in summer. Studies in Cod and Atlantic salmon have demonstrated a positive correlation between ambient temperature and measured L* value using a similar colormeter (Hiltunen et al., 2002; Stien et al., 2005; Erikson and Misimi, 2008). Considering that fresh colormeter values in the present study were collected in the field and as a result exposed to substantially different ambient temperatures, it stands to reason that this relationship may have influenced the lightness results in the present study for fresh fish fillets.

Geographic origin of the fish also had significant effects on Asian carp fillet quality. The differences in fillet quality associated with each reach may be attributed to a long list of abiotic and biotic factors, previous discussed, which cannot be clearly defined from this single study. Fish harvested from the Alton Reach were fresher upon arriving at the processing plant; however, were observed to degrade more severely during the 6 weeks of simulated frozen storage and subsequent thawing. Peoria fish, which travelled a greater distance to the processing plant, had lower Torrymeter freshness values upon arrival at the plant but held up better during frozen storage. A superior shelf life for Asian carp harvest from the PeoriaReach is further supported by the observation that Alton fish fillets had significantly higher aldehyde concentrations, indicating greater secondary degradation than in fish harvested from Peoria. Fish from both reaches of the Illinois River had similar fresh and frozen whiteness and L* values, but fish harvested from the Peoria Reach had significantly redder and yellower frozen fillet tissue, indicating a potentiallyless desirable final product by consumers (Alfnes et al., 2006).

Product quality of fish fillets is often linked to its biochemical composition. Data gathered from these analyses are used as an indication of diet composition, energy use, and overall fish health (Nettleton and Exler, 1992; Saito et al., 1999; Alasalvar et al., 2002). Overall, fish collected in the present study had similar proximate analysis when compared to previous studies in bighead, silver, and grass carp (Hakimeh et al., 2010; Hossain et al., 2004; Wu and Mao, 2008; Bowzer et al., 2013). Proximate composition, while statistically different between all three main effects (season, reach, and species), did not vary more that 1-2% with the exception of crude lipid differences between reaches. It is likely that the crude lipid in Asian carp fillets sampled from Alton harvested fish may have influenced freshness and fillet color. The observed higher lipid concentrations in Alton harvest fish may also have contributed to higher fillet aldehyde concentrations, indicating secondary degradation of lipids. Slightly higher, albeit not statistically different, lipid levels in Bighead carp fillets may have contributed to higher peroxide levels, as an indicator of primary lipid oxidation. While this potential correlation does not appear to hold true for seasonal effects, it has been long recognized that lipid oxidation is a major problem in the storage of fatty foods (Bowzer et al., 2013). The effect of higher temperatures in the summer relative to the fall harvest season is likely to be greater than the small differences observed in fillet lipid concentration. Higher temperatures enhance the negative effects of harvest stress on fillet quality (Borderías and

Sánchez-Alonso, 2011) leading to increased bacterial and enzymatic activity and greater muscle degradation (IAEA, 2000).

In personal communications with several commercial fishermen and processors in Illinois, they have indicated that Silver Carp “do not hold up” as well as Bighead Carp. These sentimentsappear to come from observations ofexternal body condition and bruising. Differences in physiology, life history, and stress responses between these two species (Cremer et al., 1980; Spataru and Gophen, 1985; Burke et al., 1986; Dong and Li, 1994; Gu et al., 1996; Xie and Chen, 2001; Cook et al., 2009)substantiate these common observations. However, contrary to the general industry dogma, results of the present study suggest Silver Carp should have a greater shelflife. Lower fillet pH, reduced Torrymeter freshness values, and increased peroxide buildup suggest Bighead Carp did not maintain quality as well under the harvest and processing conditions evaluated. While the contradictory nature of these findings relative to the general industry perception may seem problematic, it emphasizes the need to fully characterize and understand the many factors that may affect the quality of Asian carp products. Further research is needed to better quantify disparities between species as noted by commercial fishermen and processors. For example, research to correlate external body appearance to fillet product quality in Asian carp harvested from the Illinois River has not been conducted and could lead to a better understanding of how visual factors might be used to better predict quality.

CONCLUSION

Although Bighead and Silver Carp, are considered to be among the four most economically and culturally important food fish in China (Duan, et al., 2009), information on product quality is lacking. The emergence of an Asian carp industry in the mid-western Unites States introduces both economic opportunities and challenges. The current market environment supports the shipment of frozen Asian carp to China; however, lack of standardization in harvesting, hauling, and processing techniques present challenges for product quality. This research documents the effects of season, geographic origin, and species on product quality related to shelf-life and visual perception. The latter did not correlate well with predictors of shelf-life in this study. Improved shelf-life was observed for Silver Carp, fall harvested fish, and fish from the Peoria Reach. Further evaluation of commercial techniques and factors contributing to Asian carp quality are needed to maximize the potential ecological and economic benefits of this emerging industry.

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