Burnt Tuna: Conditions Leading to Rapid Deterioration in the Quality of Raw Tuna

J. L. CRAMER, R. M. NAKAMURA,
A. E. DIZON, AND W. N. IKEHARA

ABSTRACT—Burnt tuna is raw tuna which is paler and softer than normal. This study indicates that the burnt tuna condition results from muscle cell degeneration which begins prior to the death of the fish and proceeds more rapidly after death than in normal tuna. Female sex, longer fighting times, and less efficient chilling are positively correlated with the occurrence and severity of the burnt tuna condition.

Introduction

In Hawaii, raw tuna flesh which seems paler and softer than normal is characterized by buyers as being "burnt." High-quality tuna should be translucent, red, and firm. Burnt tuna, because of its poor texture, color, and slightly sour taste, while edible, is undesirable for raw consumption (as "sashimi"). It therefore commands only a fraction of the selling price of high quality tuna, depending on the extent and the severity of burn. However, the burnt condition is not absolute in extent or degree; the affected area can vary from 5 to 100 percent of the total marketable meat of the fish and range in severity from marginal to severely burnt. The variability in occurrence compounds an already difficult diagnostic problem.

The condition periodically occurs in the large (45-136 kg) tropical tunas—the yellowfin tuna, *Thunnus albacares,* and bigeye tuna, *T. obesus*—and was first brought to the attention of the National Marine Fisheries Service (NMFS) in 1974 by recreational fishermen who troll off Hawaii's Kona coast. The problem is now a major economic concern of the night handline fishery of the same island. This highly effective, cost efficient industry, found only in Hawaii and in the Philippines (Yuen, 1979), would be an excellent candidate for fishery development in export-poor Pacific island nations if the burn problem could be controlled. Whatever the causes of burn, we suspect that the problem is exacerbated by the limited chilling facilities found aboard most night handline and recreational fishing boats.

In Hawaii, traditional marketing practices delay the discovery of burn. A typical fish changes hands at least twice in the first 48 hours after death. The fisherman consigns his catch to a wholesaler who then either sells it locally or ships it to a more distant market. If the fish is sold locally, the fish is butchered and the burn is discovered relatively quickly, within 12 hours of catching. However, if it is exported, butchering usually occurs after the fish is sold to the last and most distant retailer, from 36 to 60 hours after catching. Transportation costs have thus been incurred before discovery of the condition.

Upon discovery of burn, the fisherman is required to refund a portion of the auction price to the wholesalers which is then used to defray a fraction of the costs involved in the marketing and shipping. Rebates on burnt fish were reported to range from 5 to 75 percent of the original selling price in 1977. Annual losses to the night handline fishermen were estimated to be about 16 percent of the total value of the catch (Cramer et al.)[1].

Clearly the reduction of burn through improved fishing and handling methods is an important goal and some method must be developed to identify the condition of the fish early in the marketing sequence before filleting.

These requirements formed the motivation for our work. We reasoned that our best strategy to investigate burn was to correlate quality of the fish with those measurable variables that would be likely to be responsible for, or at least indicate burn. Those correlates fell into three classes: 1) Fishing variables such as time of the year, temperature of the water, fighting time, and care of the catch; 2) biological characteristics such as sex, weight, species, and body temperature at death and after; and 3) biochemical, histological, and pH samples. We hoped that burnt fish would exhibit some differences in key characters relating to exercise or flesh quality. Thus, differences between burnt and normal tuna

J. L. Cramer was with the Honolulu Laboratory, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, 2570 Dole Street, Honolulu, Hawaii; present address: Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, P.O. Box 21, Mukilteo, WA 98275. R. M. Nakamura is with the Department of Animal Sciences, University of Hawaii (Manoa), 1800 East-West Road, Honolulu, HI 96822. A. E. Dizon is with the Honolulu Laboratory, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, 2570 Dole Street, Honolulu, HI 96812. W. N. Ikehara is with the Department of Zoology, University of Hawaii, Honolulu, HI 96822.

[1]Cramer, J. L., R. S. Shomura, and H. S. H. Yuen. 1978. The problem of burnt tuna in the Hawaiian fishery. National Marine Fisheries Service, Southwest Fisheries Center Admin. Rep. 11H, 17 p.

would indicate the causes and suggest remedies.

Materials and Methods

Fish

Bigeye and yellowfin tunas were studied in this report. Three tunas were obtained from commercial fishermen on the island of Hawaii. Seven fish were caught off Kona, Hawaii, and transported live in the baitwell to the Kewalo Research Facility (KRF) in Honolulu and two fish were held in captivity at KRF for over 6 months before being used in these studies.

The date, area of catch, fighting time, weight, species, and sex of the fish were recorded. The prechill interval (the time from landing to chilling) was also recorded.

Sampling and Testing

Temperature, blood, and muscle samples were recorded when the fish were: 1) First landed on the boat, 2) off-loaded from the boats, and 3) at 24 hours after off-loading.

Blood was obtained by cardiac puncture immediately after boating the fish using silicone-coated vacutainers (Kimble-Terumo, Elkton, MD.).[2] Captive fish were bled just prior to killing, and 2 ml of whole blood were immediately mixed with 2 ml of 15 percent perchloric acid for glucose and lactate determinations. The serum was separated from the remaining blood and frozen for later testing.

A coring tool was used to obtain tissue samples from the deep muscle near the vertebral column. Tissues were frozen on dry ice or fixed in Dietrich's solution. The latter tissues were processed to obtain Hemotoxylin and Eosin stained sections for microscopic examination.

An electronic thermometer with a 12 cm probe was used to obtain temperatures of deep (11 cm) or superficial (just under the skin) tissues of fish.

Fish held in captivity or transported live to KRF were placed in ice water for 4-8 hours after killing to simulate normal commercial procedures for treatment of fish prior to off-loading.

The handling of fish during the first 24 hours after off-loading from the boats was evaluated and categorized. The fish were designated to have received: 1) Excellent treatment when stored in ice water at 0°C, 2) fair treatment when stored in refrigerators at 5°C, and 3) poor treatment when stored at ambient temperature of 28°C.

After the fish were auctioned and quartered, the flesh was graded and scored on the basis of color and texture as: Excellent, 1 point; good, 2 points; marginal, 3 points; poor, 4 points; and very poor, 5 points. These subjective evaluations were corroborated by discussions with the auctioneer and correlated with the price received per pound of fish.

Tests

Blood lactate and glucose concentrations were determined by enzymatic analysis utilizing the conversion of NAD to NADH as described by Burgmeyer (1974). A creatine phosphokinase (CPK) assay was also conducted following the method of Burgmeyer (1974). The above assays were performed at the University of British Columbia, Vancouver, with the direction and assistance of P. Hochachka and J. Balantyne.

The pH of muscle tissue was determined by titration and the amount of potassium carbonate required to lower the pH of the muscle suspension to a pH of 5.6-6.0. A pH meter with a 4 mm diameter probe was used to determine the pH of the midsection and tail muscle tissue of yellowfin or bigeye tuna on the auction floor. The pH was also determined by pH meter for macerated muscle tissue suspended in distilled water.

Statistical Analysis

Correlations of quantitative variables were determined by simple regression analysis. Correlations involving one or more nonparametric variables were determined by using Spearman's correlation rank test (Snedecor and Cochran, 1967).

The significance of differences between mean values were determined using a t test for the differences of means (Snedecor and Cochran, 1967).

Results

The fighting time and other relevant data on the 12 fish used in this study are recorded in Table 1. Significant ($P<0.05$) positive correlations were found between fighting time and concentrations of blood lactate (Fig. 1) and blood glucose (Fig. 2) at death and between fighting time and tissue lactate (Fig. 3) when fish were being off-loaded from the boats. A negative correlation was found between fighting time and relative acidity of muscle at off-loading (Table 2). The correlations of these parameters are also indicated in Table 2.

There was a significant difference ($P<0.05$) between sexes in quality of flesh of fish over 30 kg in weight (Table 3). The flesh of female fish was more often of low quality. An interaction was found between

Table 1.—Data on fish studied.

Date caught (1978)	Area caught	Fighting time (min.)	Wt. (kg)	Species	Sex
21 Aug.	Hilo[1]	9	115.8	*T. albacares*	M
21 Aug.	Hilo[1]	10	63.6	*T. albacares*	F
27 Sept.	Kewalo[2]	15	10.8	*T. albacares*	F
27 Sept.	Kona[2]	9	5.2	*T. obesus*	M
27 Sept.	Kona[3]	9	4.4	*T. obesus*	M
27 Sept.	Kona[3]	4	3.4	*T. albacares*	F
27 Sept.	Kona[3]	4	3.5	*T. albacares*	F
27 Sept.	Kona[3]	12	3.7	*T. albacares*	M
27 Sept.	Kona[3]	18	3.6	*T. albacares*	M
27 Sept.	Kona[3]	31	3.5	*T. albacares*	F
17 Oct.	Kewalo[2]	0	9.4	*T. albacares*	F
23 Oct.	Kona[1]	15	50.4	*T. obesus*	F

[1]Sampled at sea.
[2]Captive fish.
[3]Transported live to KRF.

[2]Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

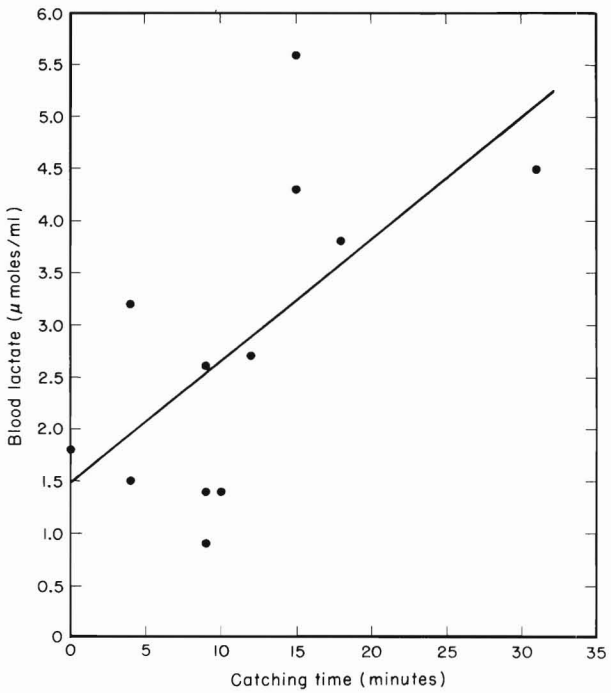

Figure 1.—Correlation between catching time (fighting time) and concentration of blood lactate at death. Line fitted by least squares methods.

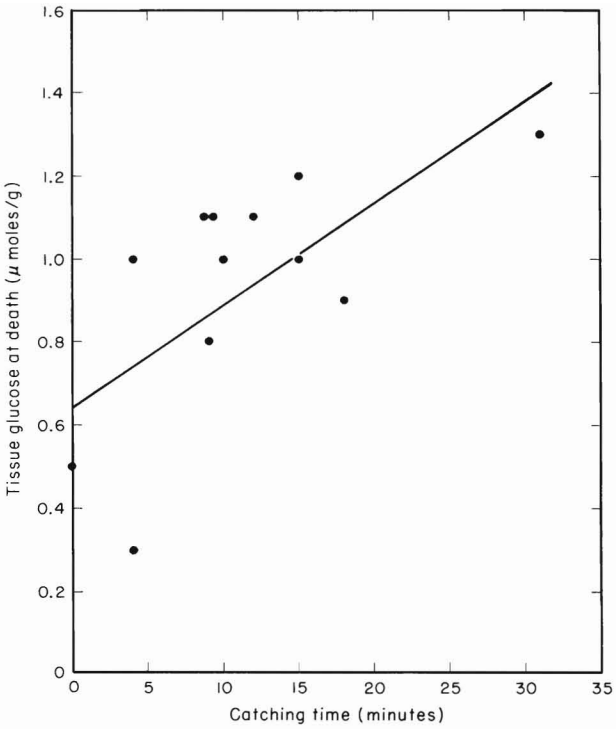

Figure 2.—Correlation between catching time (fighting time) and concentration of glucose at death. Line fitted by least squares methods.

Table 2.—Correlations between fighting time (FT), blood lactate level at death (BL), tissue glucose level at death (TGa), tissue lactate level at off-loading (TLb), relative acidity in tuna tissues at off-loading (TAb), and quality of fish at quartering (Q).

Independent variable	Dependent variable	Correlation
FT	BL	[1]0.64
FT	TGa	[1]0.69
FT	TLb	[1]0.59
FT	TAb	[1]-0.66
BL	Q	[2]0.82

[1]Significant at the 0.05 percent level.
[2]Significant at the 0.01 percent level.

Table 3.—The effect of size and sex on flesh temperature and flesh quality.

Body wt. (kg)	Sex	Temperature (°C) Average	Temperature (°C) Range	Flesh quality[1] Average	Flesh quality[1] Variance
<11	M	27.5	26.9-28.4	2.4	1.3
<11	F	27.7	26-29.5	2.8	0.7
>30	M	29.6	29-31	1.5	1.0
>30	F	29.7	27-31	2.8	1.6

[1]1 = Excellent, 2 = good, 3 = marginal, 4 = poor, and 5 = very poor.

Table 4.—Interactions between blood lactate levels at death and 24-hour treatments after off-loading.

Blood lactate micromole/ml	Quality at death[1]	Treatment[2]	Quality at quartering[1] (24 h after death)
0.91	1	Excellent	1
1.42	1	Excellent	1
1.42	1	Poor	3
1.47	1	Fair	2
1.82	2	Fair	2
2.58	2	Fair	2
2.67	1	Fair	2
3.20	2	Poor	3
2.83	1	Poor	4
4.25	3	Poor	4
4.49	2	Fair	3
5.64	2	Poor	4

[1]Quality was determined histologically and was scored as follows: 1 = Excellent, 2 = good, 3 = marginal, 4 = poor, and 5 = very poor.
[2]Excellent = stored in ice water at 0°C, fair = stored in refrigerators at 5°C, and poor = stored at ambient temperature of 28°C.

treatment after off-loading and concentrations of blood lactate at death (Table 4). Low lactate and good treatment resulted in excellent quality flesh; low lactate and poor treatment or high lactate and fair treatment resulted in marginal quality flesh; and high lactate and poor treatment produced poor quality flesh.

In some cases, there was excellent correlation between pH of muscle tissue and quality of tuna flesh (Table 5) while in other instances lower pH could not be correlated with poor quality flesh (Table 6, Fig. 4). These differences are probably due to differing temperatures and durations before auction (Nakamura et al., 1977).

No significant correlations were found between deep body temperatures and quality of fish or results of biochemical tests. Nor could signifi-

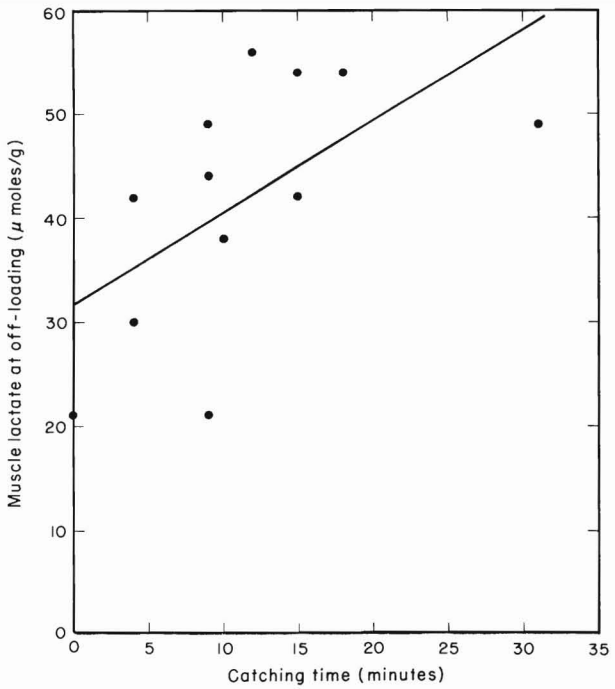

Figure 3.—Correlation between catching time (fighting time) and muscle lactate at off-loading. Line fitted by least squares methods.

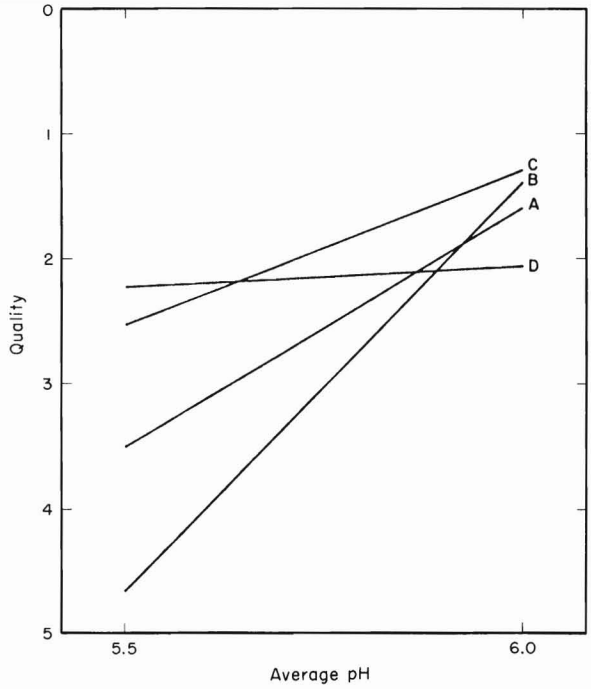

Figure 4.—Correlation between pH and auction quality (1 = excellent, 2 = good, 3 = marginal, 4 = poor, and 5 = very poor) of: A) all fish sampled, B) fish sampled on 28 July, C) Honolulu fish sampled on 10 August, and D) Hilo fish sampled on 10 August.

Table 5.—Quality and pH of midsections and tails of yellowfin tuna at the Honolulu fish auction, 28 July 1978.

	Tuna quality									
	Excellent		Good		Marginal		Poor		Very Poor	
	Mids	Tail	Mids	Tail	Mids	Tail	Mids	Tail	Mids	Tail
	6.0	6.1	6.0	6.2	5.6	5.7	5.6	5.6	5.4	5.5
	6.0	6.0	5.9	5.6	—	—	5.7	5.8	5.5	5.6
	6.0	5.7	5.9	5.9	—	—	5.8	5.9	5.7	5.8
	5.8	5.9	5.8	5.9	—	—	5.7	5.9	—	—
	6.0	5.6	—	—	—	—	5.6	5.7	—	—
	5.8	6.0	—	—	—	—	—	—	—	—
	5.9	6.0	—	—	—	—	—	—	—	—
Mean	5.93	5.90	5.90	5.90	—	—	5.68	5.78	5.53	5.63
Variance	0.01	0.03	0.01	0.06	—	—	0.01	0.02	0.03	0.03

Table 6.—Quality and pH of midsections and tails of yellowfin tuna at the Honolulu and Hilo fish auctions, 10 August 1978.

	Tuna quality					
	Excellent		Good		Poor	
	Mids	Tail	Mids	Tail	Mids	Tail
	Honolulu fish					
	5.6	5.6	5.5	5.6	6.0	5.5
	5.6	5.7	5.7	5.7	5.9	5.8
	5.9	5.9	5.6	5.7	—	—
	5.6	5.7	—	—	—	—
	5.7	5.8	—	—	—	—
Mean	5.68	5.74	5.60	5.67	5.95	5.65
Variance	0.2	0.01	0.01	0.00	0.08	0.02
	Hilo fish					
	5.8	5.9	5.8	5.8	5.7	5.8
	6.0	5.9	5.7	5.8	5.9	5.8
	—	—	5.9	5.9	—	—
	—	—	5.7	5.8	—	—
	—	—	5.9	5.9	—	—
	—	—	6.0	6.0	—	—
	—	—	5.8	5.8	—	—
	—	—	6.0	6.0	—	—
	—	—	6.0	6.1	—	—
	—	—	6.0	5.9	—	—
	—	—	6.1	6.1	—	—
	—	—	5.9	5.9	—	—
Mean	5.90	5.90	5.90	5.92	5.80	5.80
Variance	0.02	0.00	0.02	0.01	0.02	0.00

cant correlations be found between the pre-chill interval and quality of fish or results of biochemical tests of blood and tissues.

Histopathologic studies of muscle from a limited number of fish revealed the following: 1) Inflammatory changes were not seen, suggesting that all changes occurred shortly before or immediately after death; 2) edema was seen in muscle obtained at the time of boating; 3) extensive edema and muscular degeneration were seen in burnt fish at the time of auctioning; and 4) tissue gram stain showed that bacteria was associated with the muscular degenerative changes.

Discussion

As suspected by tuna fishermen, the results of this study suggest that the care and handling of fish after being caught is partly related to the subsequent quality of the flesh of the tuna (Table 4). However, the pathogenesis of burnt tuna may also be related to physiological changes in the fish during the struggle while being caught. Fighting time was related to blood lactate and glucose levels at death (Fig. 1, 2). The edema (abnormal accumulation of fluid) in muscle seen in histopathological studies of biopsies obtained at death also suggest that the struggle of fish being caught may predispose the flesh to subsequent degeneration. The lack of inflammatory changes at that time indicates that the condition is not developed prior to being hooked.

A hypothesis on the mechanism for the development of burnt tuna is as follows.

1) The struggle of fish while being caught may result in muscle edema, the severity depending on the intensity of the struggle. (Longer and more intensive struggling results in higher blood levels of glucose and lactate.)

2) The edema fluid of muscle presents a good medium for bacterial growth.

3) Chilling of fish after catching determines the temperature of the deeper portions of the fish muscles, which are least affected by external cooling procedures.

4) Poor chilling procedures allow higher temperatures in muscle, allowing bacteria to grow more profusely and resulting in increasing degrees of burn in the deeper areas of the muscle mass.

The most reliable diagnostic method may be histopathologic examination of biopsy specimens obtained from deep muscle tissues, flash frozen, sectioned with a cryostat at the auction, stained and examined. All of this can be accomplished in 0.5-1 hour. With the exception of tests made on blood samples collected at the time of catching, biochemical tests were not useful in prediction and diagnosing the burnt tuna condition of unquartered tuna.

A stress-induced abnormality which occurs in hog muscle known as porcine stress syndrome (Winstanley, 1979) seems similar in some characteristics to burnt tuna. Both conditions result in pale and soft muscles. It is possible that there may be related causes for the two conditions.

It is obvious that further studies on burnt tuna are necessary. The small number of fish sampled in this study (12) resulted in possible leads and solutions, but precludes strong and definitive statements on this condition. It is likely that improved handling and chilling procedures from the time of capture may help to reduce the incidence of burnt tuna.

Acknowledgments

This research was funded by a National Marine Fisheries Service contract. Technical assistance and laboratory space were provided by the University of Hawaii (Manoa), University of British Columbia, and the NMFS Southwest Fisheries Center's Honolulu Laboratory. Expertise in fishing and fish handling, without which this study could not have been completed, were provided by fish wholesalers and fishermen in Hilo, Kona, and Honolulu, Hawaii.

Literature Cited

Bergmeyer, H. U. 1974. Methods of enzymatic analysis. 2:437, 787. Acad. Press., N.Y.

Nakamura, K., Y. Fujii, and S. Ishikawa. 1977. Turbid meat of tuna - I. Study on its possible causes. Bull. Tokai Reg. Fish. Res. Lab. 90.

Snedecor, G. W., and W. G. Cochran. 1967. Statistical methods. Iowa State Univ. Press, Ames, 593 p.

Winstanley, M. 1979. A cure for stress. New Sci. 84:594-596.

Yuen, H. S. H. 1979. A night handline fishery for tunas in Hawaii. Mar. Fish. Rev. 41(8):7-14.