

Sensory, Microbiological and Biochemical Quality of black pomfrets (*Pampus niger*) stored in dry ice and ice

D. Sukumar, G. Jeyasekaran*, R. Jeya Shakila, R. Anandaraj and P. Ganesan,

Department of Fish Processing Technology, Fisheries College and Research Institute
Tamilnadu Veterinary and Animal Sciences University
Thoothukudi 628 008, India

The sensory, microbiological and biochemical quality of black pomfrets (*Pampus niger*) stored in different ice packages was investigated. Pomfrets packed in dry ice at the ratio of 1:1 (w/w) were found to be sensorially suitable for consumption when they were stored for 24 h without re-icing. Pomfrets stored in a combination of dry ice and ice at the ratio of 1:0.2:0.5 (w/w/w) and in ice at the ratio of 1:1 (w/w) (as control) were acceptable up to 18 h and 12 h, respectively. Total bacterial load ranged from 10^4 to 10^7 cfu/g, while total psychrophiles from 10^3 to 10^6 cfu/g. Total lactic acid bacteria varied from 10^3 to 10^5 cfu/g. TVB-N and TMA-N contents were within the permissible limit in pomfrets stored in dry ice. Hypoxanthine (Hx) contents ranged from 3.46 to 8.96 mg/100g and FFA content varied from 10.35 to 54.34% as oleic acid. Lowest temperature of -11°C was recorded in pomfrets stored in dry ice. Packages I and II had 100% CO_2 inside after one hour of storage.

Key words : Sensory, microbiology, biochemistry, shelf life, *Pampus niger*, dry ice

A very common method of retarding fish spoilage in India, and in other tropical countries, is to store it in chilled medium (Surendran *et al.*, 1989). The most widely used chilling medium for preserving fresh fish is ice. Most of the exporters use only crushed ice for chilling and transporting fresh fish at ratio of 1:1, and sometimes it is even higher in tropical condition (Lima dos Santos *et al.*, 1981), which results in exorbitant transportation cost and leakage problems due to melting of ice. When the surrounding environment of the product is modified to reduce oxygen concentration, the shelf life is increased considerably because of further reduction in the rate of chemical oxidation by oxygen and in the growth of aerobic microorganisms (Stiles, 1991).

Dry ice has recently gained popularity in

India for the rapid transportation of fresh fish by air by reducing the temperature rapidly as well as modifying the packing environment with CO_2 (Carbon dioxide) is the most important gas used in modified atmospheric packaging of fish. Because of its bacteriostatic and fungistatic effect, it inhibits growth of many spoilage bacteria (Sivertsvik *et al.*, 2002). Dry ice acts as coolant in the present trends of shipping of fresh seafoods (Shoemaker, 1990) and it acts as insulant enveloping the fish upon evaporation (Putro, 1989). Regenstien & Regenstien (1991) have suggested that dry ice could be used for air shipping of fresh fish, as leakage is the main problem associated with the packing of fish with ice. Recently, dry ice is mixed with ice to save shipping weight, cost and increase the efficiency of ice. Several exporters use dry ice in

*Corresponding author: E-mail-ttn_jerosh99@sancharnet.in

combination with ice without any scientific basis for fresh fish transportation. However, it has been earlier reported that combination of fish, dry ice and ice at the ratio of 1:0.2:0.5 (fish to dry ice to ice) is efficient for keeping fresh fish in good quality with better shelf life (Sasi *et. al.*, 2000). It has also been reported that the fish, Emperor breams stored in the dry ice and ice combination was superior when compared to storage in ice (Jeyasekaran *et. al.*, 2004). Since pomfret is an exportable fish in chilled condition from India and it fetches higher foreign exchange, the present study was carried out to find out the quality of black pomfrets (*Pampus niger*) in relation to their sensorial, microbiological and biochemical quality and shelf life, when they were chilled in a combination of dry ice and ice as well as in ice.

Materials and Methods

Black pomfrets (*Pampus niger*) procured from fishing harbour, Thoothukudi were immediately brought to the laboratory in insulated containers and washed with potable water. Whole fish had an average length of 19 cm and weight of 135 g. Fish was divided into 3 lots and each lot had a weight of 16 kg. There were eight packs in each lot. First lot was packed with dry ice (Thermosafe Dry ice Machine, USA) at the ratio of 1:1, second lot with a combination of dry ice and ice at 1:0.2:0.5 ratio (Sasi *et. al.*, 2000) and the third lot with ice (Ziegra Flake ice Maker, Germany) at 1:1 ratio (Lima dos Santos *et. al.*, 1981), which served as control. They were designated as packages I, II and III. Gloves were worn during handling of ice and fish. Care was taken to avoid direct contact of fish with ice as well as with dry ice by wrapping dry ice in kraft paper pouches and ice in polythene bags. Packages were wrapped in polythene bags (Polypropylene, 200 gauge), placed in styrofoam boxes and sealed airtight with cellophane tape. The boxes were stored at room temperature ($33 \pm 2^\circ\text{C}$) without reicing. One pack from each lot was analyzed in triplicate for sensory, microbiological and biochemical quality immediately after packing (1 h) and then at an interval of 6 h until they were organoleptically unacceptable.

Sensory characteristics and overall acceptability of pomfrets were assessed by a panel of six members belonging to the Faculty of Fisheries College and Research Institute, Thoothukudi on the basis of ten point scale on each sampling. Sensory characteristics studied included general appearance, odor and texture of fish. Scale employed for evaluating sensory quality of chilled pomfrets is given in Table 1, which was developed based on the guidelines given by Lima dos Santos *et.al.* (1981). The scores were given in the decreasing order scale with 10-9 for excellent, 8-7 for good, 6-5 for fair and acceptable, 4-3 for poor and 2-1 for very poor. The mean of the scores given by the panel represented the overall sensory quality (Huss, 1988). A score of 3 to 4 constituted unacceptable.

Microbiological analysis carried out in this study included total bacterial count (TPC), total psychrophiles and total lactic acid bacteria. Media used in this study were obtained from Hi-Media, Mumbai, India. Fish muscle was cut into very small pieces using sterile knife and forceps and pooled together. Then, 25 g was taken from this pool and homogenized using 225 ml sterile physiological saline (0.85% NaCl) and further dilutions were carried out in the same diluent. (APHA, 2001). Appropriate dilutions were spread plated onto Trypticase soya agar (TSA) for the enumeration of total bacterial count and total psychrophilic count. The plates were incubated at room temperature for 24 h for the enumeration of total bacterial count, whereas they were incubated under refrigerated condition (5°C) for 7 days for the enumeration of psychrophiles. Double-layer pour plate technique was followed for the enumeration of total lactic acid bacteria using Lactobacillus MRS agar (USFDA, 2001). Inoculated plates were incubated at room temperature for 72 h. After appropriate incubation, number of suspected colonies developed on the plates were counted and expressed as cfu/g.

Biochemical quality parameters studied include total volatile base nitrogen (TVB-N), trimethylamine nitrogen (TMA-N), free fatty acid (FFA) and hypoxanthine (Hx). TVB-N and TMA-N contents were determined by the

Table 1. Scale employed for sensory evaluation of black pomfrets (*Pampus niger*) stored in dry ice and ice

General appearance	Texture	Odour	Score
Bright opalescent sheen, cornea transparent, eyes perfectly fresh, convex black pupil, bright red gills, slime transparent, no bleaching	Very firm, elastic to finger touch, fish not yet in rigor, scales very firmly attached to skin	Fresh sea weedy odour	10
Eye fresh, slightly convex, black pupil, red gills, slime translucent, cornea translucent	Moderately firm, elastic, fish in pre-rigor	Loss of fresh sea weediness, shell fish odour	9
Eyes flat, very slight gray pupil, dull red gills, slightly translucent cornea	Firm, moderately elastic, scales firmly attached to skin, fish in rigor	No odours, neutral odour	8
Slime translucent, eyes flat, slight gray pupil, loss in red colour of gills	Slightly firm, slightly elastic, fish in rigor	Slightly musty, mousy, milky, garlic or peppery odour	7
Eyes slightly sunken, gray pupil, slight opalescent cornea, discolouration of gills, some mucus, outer slime slightly opaque	Slight soft, some grittiness near tail, fish passing out of rigor	Bready, malty, beery, yeasty odour	6
Eyes sunken, pale pupil, opaque cornea, slime opaque, some mucus, light brown gills	Moderately soft, moderate grittiness, slightly loose scales, fish in post rigor	Lactic acid, sour milk or oily odour	5
Eyes completely sunken, milky white pupil, opaque cornea, brown gills	Soft, definite grittiness, slightly loose flesh, scales easily removable	Acetic or butyric acid, grassy, slightly sweet, sweetly or chloroform odour	4
Eyes completely concave, head shrunken with thick slime, gills exhibit bleaching and dark brown discolouration	Very soft, marked grittiness, loosened flesh, scales easily rubbed off the skin	Stale cabbage water, wet matches, phosphine like odour	3
Eyes completely concave, shrunken head and body, cornea and pupil milky white, body covered with yellowish mucus or slime	Very soft and flabby, slight retaining of finger indentation, flesh easily torn	Ammoniacal with strong odours	2
Eyes loose and completely concave, body and head shrunken and discoloured, bloom completely gone, thick yellowish slime or mucus	Extremely soft and flabby, strong retention of marks, flesh very easily torn	Indole, faecal, H_2S , strong ammoniacal and putrid odours	1

Conway micro-diffusion method (Cobb *et.al.*, 1973). Free fatty acid content was determined by the method described by Pearson (1968). Hypoxanthine content was estimated using the method of Burt (1976).

Physical parameters studied were temperature and gas composition. Changes in temperature of all the packages were recorded by using Ultrafreezer temperature probe (Consort Model T 852, Belgium). Gas composition of different packaging environment was measured by gas analyzer (PBI Dansensor CheckMate 9900, Denmark).

Analysis of variance (ANOVA) was performed using standard statistical package (SPSS 10.0) to examine whether any significant difference exists between different treatments, with respect to various quality characteristics at 5% level.

Results and Discussion

Overall sensory scores of black pomfrets (*Pampus niger*) stored in packages I, II and III are shown in Fig.1. Initially the fish exhibited fresh seaweedy odour, shiny appearance, bright red gills, bright eyes, very firm texture and reddish white meat. No remarkable change was observed in packages II and III after 1 h, whereas the fish in package I was slightly frozen near the dry ice contact area due to a drastic fall in temperature. After 6 h, package II exhibited slight seaweedy odour, bright eyes and shiny appearance and package III lost its seaweedy odour and exhibited the onset of dull eye. After 12 h, of storage, package III exhibited slight ammoniacal odour, slight yellowish meat and light brown gills with firm texture. No noticeable odour was observed in package II, but the meat colour was slightly better than package III. After

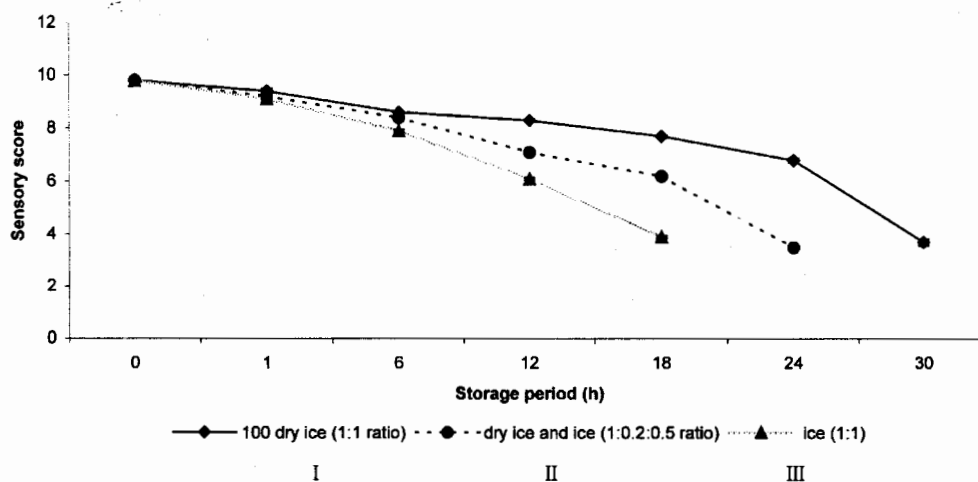


Fig. 1. Changes in the sensory quality of black pomfrets (*Pampus niger*) stored in dry ice and ice

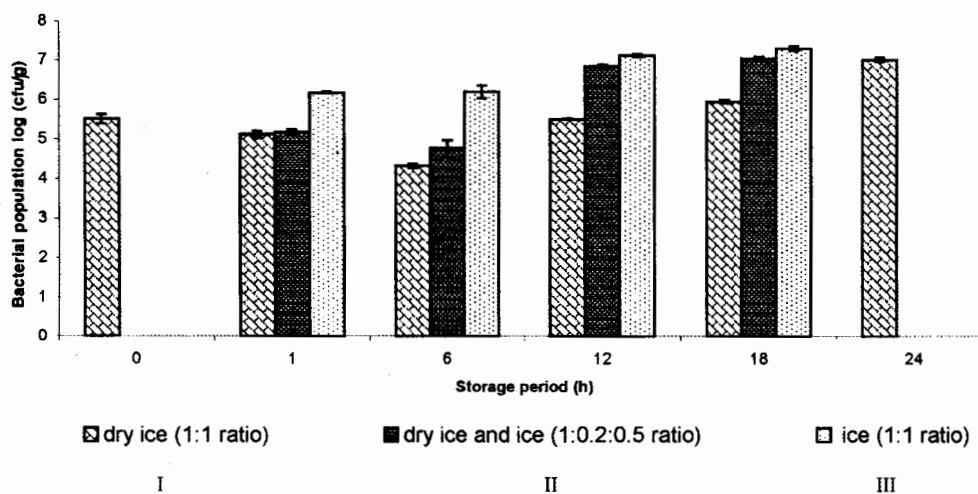


Fig. 2. Changes in total bacterial count log (cfu/g) of black pomfrets (*Pampus niger*) stored in dry ice and ice

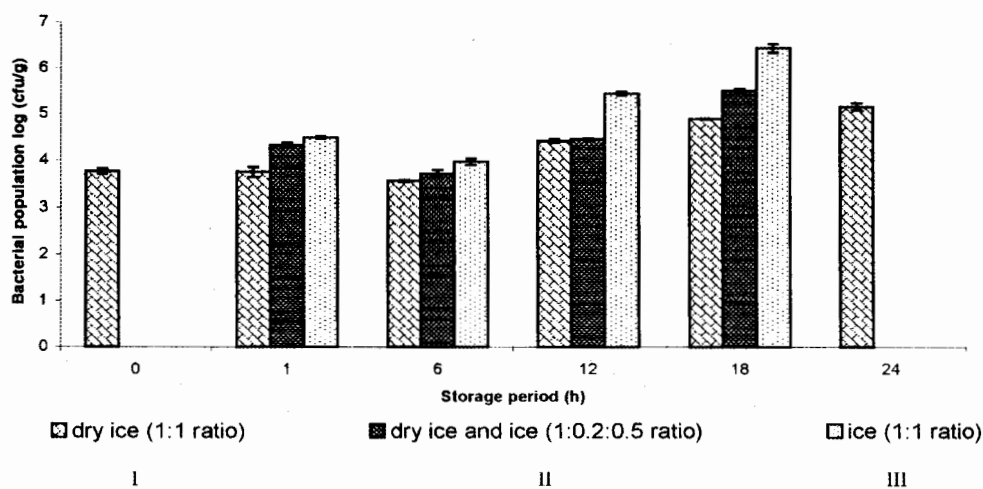


Fig. 3. Changes in total psychrophilic count log (cfu/g) of black pomfrets (*Pampus niger*) stored in dry ice and ice

18 h, package III exhibited strong ammoniacal odour, yellowish green meat colour, soft texture and discoloured gills and found to be unacceptable. Package II had slight ammoniacal odour, slight firm texture and light brown gill colour. On the other hand, package I was completely frozen after 6 h, of storage. After 12 h, fish became normal in condition and had shiny flat eye. Slight mucus layer was observed over the fish and gill colour became brownish after 18 h of storage. After 24 h, package II was sensorially unacceptable with strong ammoniacal odour. However, package I exhibited similar characteristics of package II when it was at the 18th hour, and was organoleptically unacceptable after 30 h. It was earlier reported that combination of dry ice and ice extended the shelf life of seer fish when compared to ice (Sasi *et al.*, 2003). Sensory results of salmon (*Salmo salar*) steaks showed shelf life extension of 6 d under 20% CO₂ enriched atmosphere, when compared with air (De la Hoz *et al.*, 2000). Scott *et al.* (1986) observed the shelf life extension of 9 days in snapper (*Chrysophrys auratus*) when stored in 100% carbon dioxide atmosphere at -1°C when compared to normal atmospheric storage. In this study, an increase in shelf life to a tune of 100% was obtained for the pomfrets stored in dry ice when compared to its storage in ice. A significant difference ($P < 0.05$) was observed in the sensory scores between different ice packages of fish.

Changes in total bacterial count of black pomfrets stored in packages I, II and III are given in Fig. 2. Initial bacterial count was 10⁵ cfu/g and the same was observed after 1 h of storage in packages I and II and after 6 h, the population was reduced by one log. Clark & Lentz (1969) reported that the application of CO₂ gaseous environment inhibits bacterial growth during the lag phase. Exposure to low temperature also inhibits bacterial growth (Jay, 1987). On further storage, the population increased gradually and reached to 10⁷ cfu/g at the end of storage period in packages I and II. The same trend was observed by Jeyasekaran *et al.* (2004) when emperor breams (*Lethrinus miniatus*) were stored in a combination of dry ice and ice. On the other hand, bacterial population of fish packed in dry

ice increased from 1 h onwards and reached 10⁷ cfu/g at the end of storage period. The changes in total bacterial population was found to be significant ($P < 0.05$).

Changes in total psychrophiles of black pomfrets stored in packages I, II and III are presented in Fig. 3. Fresh pomfrets exhibited an initial psychrophilic count of 10³ cfu/g, which increased by one log on the first h of storage in packages II and III and on the 6th h, it reduced by one log. On further storage, the psychrophiles

Table 2. Changes in the temperature profiles of black pomfrets (*Pampus niger*) stored in dry ice and ice

Time (h)	Temperature profile (°C)			Storage room
	I	II	III	
0	11.7	13.2	10.6	33.4
1	-1.0	3.6	8.0	32.8
2	-2.0	1.6	9.0	32.4
3	-5.4	1.3	9.7	32.2
4	-9.5	1.6	10.0	32.0
5	-11.0	2.2	10.1	31.8
6	-11.0	2.9	10.5	31.9
7	-8.1	4.3	10.8	32.0
8	-6.5	5.2	11.9	32.3
9	-4.0	7.4	15.4	32.8
10	-3.0	8.8	17.4	33.5
11	2.3	13.5	19.5	34.1
12	-1.8	16.6	21.1	34.4
13	-1.4	19.8	23.1	35.1
14	-0.9	22.0	24.3	33.6
16	-0.4	23.6	25.6	34.4
17	0.7	24.9	26.7	35.0
18	5.7	26.4	27.8	34.8
19	12.9	28.7	29.5	34.3
20	15.2	29.1	30.0	34.1
21	18.7	30.0	30.4	33.9
22	21.3	30.6	31.0	33.2
22	23.3	31.1	31.3	32.9
23	25.4	31.7	31.8	32.9
24	26.9	32.1	32.0	33.2
25	28.6	*DC	*DC	33.5
26	29.9			33.5
27	31.1			32.6
28	32.0			32.6
29	32.6			32.8
30	33.0			33.1

*DC- Discontinued

increased gradually and reached to 10⁵ and 10⁶ cfu/g in packages II and III, respectively. Jeyasekaran *et al.* (2004) observed a total psychrophilic population of 10⁴ cfu/g at the end of storage period when emperor breams were stored in a combination of dry ice and ice. In the case of fish packed in dry ice, the initial psychrophilic population was maintained up to 6th h and on further storage, the population

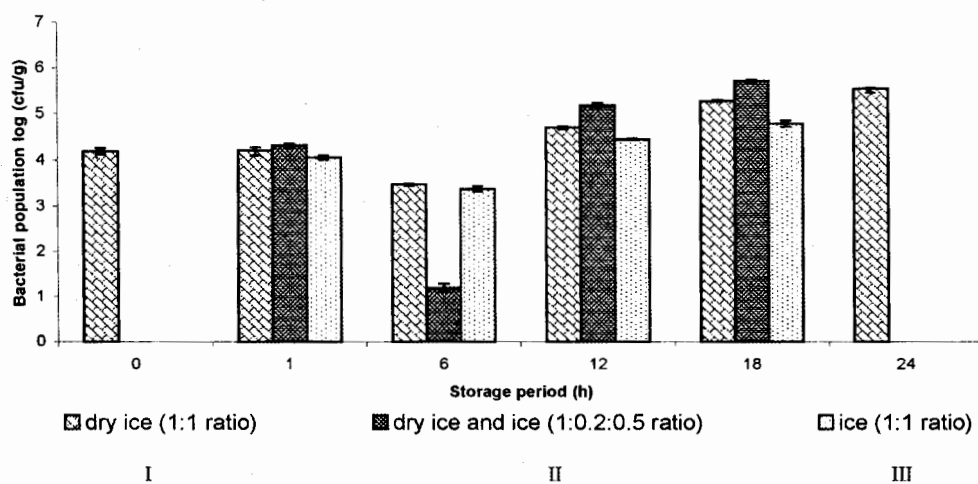


Fig. 4. Changes in total lactic acid bacterial count log (cfu/g) of black pomfrets (*Pampus niger*) stored in dry ice and ice

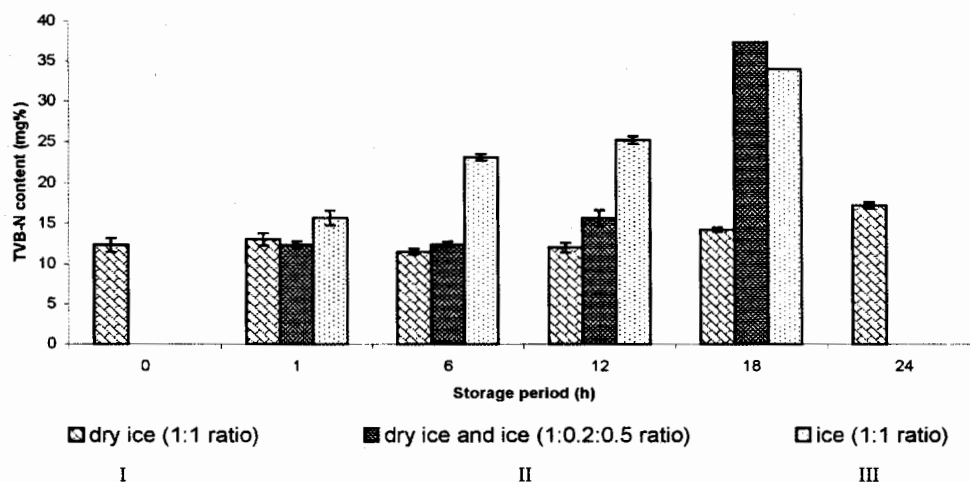


Fig. 5. Changes in TVB-N content of black pomfrets (*Pampus niger*) stored in dry ice and ice

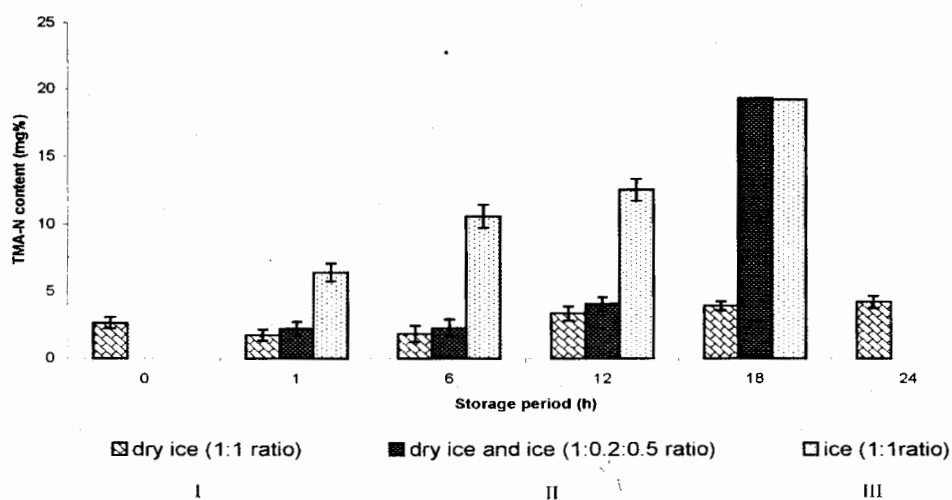


Fig. 6. Changes in TMA-N content of black pomfrets (*Pampus niger*) stored in dry ice and ice

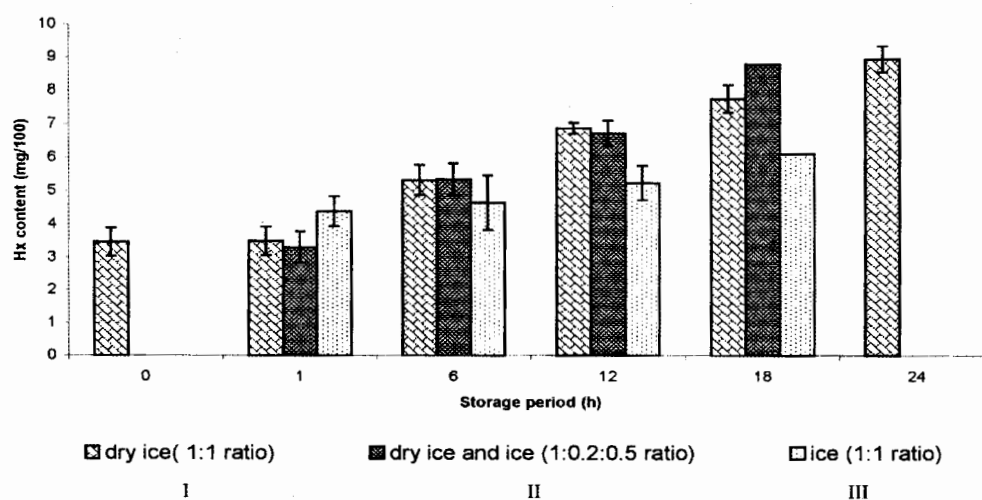


Fig. 7. Changes in Hx content of black pomfrets (*Pampus niger*) stored in dry ice and ice

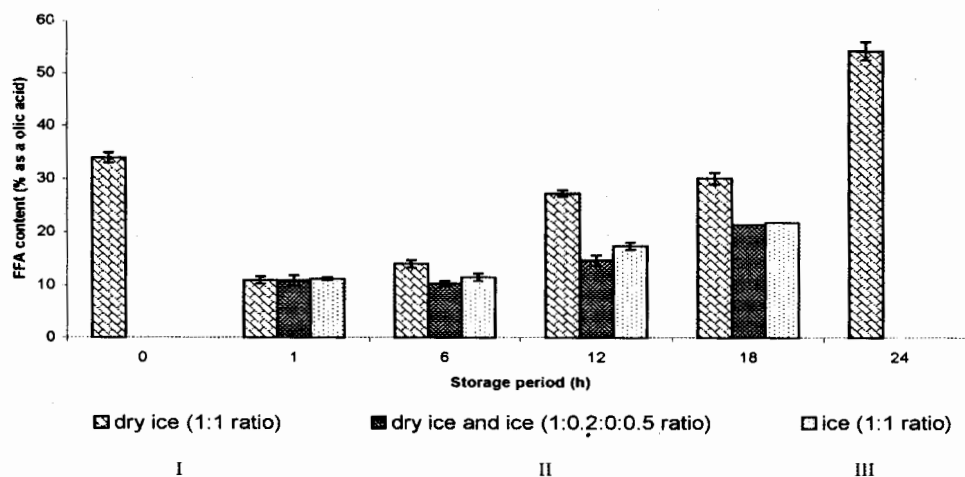


Fig. 8. Changes in FFA content of black pomfrets (*Pampus niger*) stored in dry ice and ice

increased and reached to 10^5 cfu/g on the 30 h of storage. A significant difference ($P < 0.05$) was also observed on psychrophilic population between the different packages.

Changes in total LAB of black pomfrets stored in packages I, II and III are shown in Fig. 4. Initial lactic acid bacterial population was 10^4 cfu/g, which maintained on the fast h in packages I and II and up to 6th h in package II. On the 6th h of storage, the f population reduced by a log in packages I and III, and it has reached to 10^5 cfu/g at end of the storage. De la Hoz *et.al.* (2000) observed that the growth of lactic acid bacteria was not promoted by the enrichment of the atmosphere with 20% CO₂, although it resulted in a greater number of this group in the

microbiota responsible for the spoilage. On the 12th h, the population was 10^4 cfu/g in package I and III, which maintained in package III at the end of storage period. In the case of packages I and II, the lactics population at the end of storage period was one log higher (10^5 cfu/g) when compared to package III. The equivalent result was also observed by Sasi *et.al.*, (2003) in seerfish (*Scomberomorus commersonii*) stored in dry ice and stated that dry ice provided a favorable environment for the growth of LAB.

Changes in TVB-N content of black pomfrets stored in packages I, II and III are shown in Fig. 5. Initial TVB-N content was 12.33 mg%, which increased gradually during storage and attained the maximum levels of 34.01 mg%

Table 3. Changes in gas composition of black pomfrets (*Pampus niger*) stored in dry ice and ice

Storage period (h)	Package I			Package II			Package III		
	O ₂ (%)	CO ₂ (%)	N ₂ (%)	O ₂ (%)	CO ₂ (%)	N ₂ (%)	O ₂ (%)	CO ₂ (%)	N ₂ (%)
0	21.3	0.5	78.2	21.3	0.5	78.2	21.3	0.5	78.2
1	0.026	100	0.0	0.034	100	0.0	20.6	1.2	78.2
6	0.022	100	0.0	6.99	66.5	26.5	20.8	0.7	78.5
12	5.69	73.2	21.2	14.3	31.1	54.6	20.2	1.6	78.2
18	11.4	46.0	42.6	15.7	10.9	73.4	17.4	4.8	77.8
24	17.7	16.0	66.3	*DC	*DC	*DC	*DC	*DC	*DC
30	*DC	*DC	*DC	**ND	**ND	**ND	**ND	**ND	**ND

*DC- Discontinued, **ND -Not Detected

on the 18th h of storage in packages III. Jayaweera *et.al.* (1980) reported a TVB-N value between 30 and 40 mg% in iced silver belly at the beginning of spoilage. In package II, initial content reduced slightly on the 1 h, but after that, it increased gradually and reached a higher level of 37.33 mg%. In the case of package I, slight increase in TVB-N content was observed on the 1 h, and further the TVB-N content reduced to 11.51 mg% on the 6 h. But after that, it slowly increased to 17.24 mg% on the 24 h of storage. The difference observed in three different treatments were found to be significant ($P < 0.05$). Sasi *et al.* (2000) reported that the formation of TVB-N and TMA-N was comparatively less in the sardines stored in 20% dry ice and 50% water ice. Dalgaard (2000) reported that the rejection limit of 30 to 35 mg% for TVB-N varied with species and processing condition.

Changes in TMA-N content of black pomfrets stored in packages I, II and III are given in Fig. 6. Fresh fish had an initial TMA-N content of 2.67 mg%. On the first hour, slight decrease in content was observed in packages I and II, whereas in package III, it increased to 6.44 mg%. Further decrease in TMA-N content was observed in package II on the 6 h and on further storage, TMA-N content increased gradually and reached a value of 19.31 mg% at the end of the storage. On the other hand, in packages I and III, it gradually increased from 1 h onwards and reached a level of 4.24 and 19.24 mg%, respectively at the end of storage period. Differences in the TMA-N content were significant ($P < 0.05$) between the iced packages. LeBlanc & LeBlanc (1992a) also found that the

cod and winter flounder fillets superchilled with carbon dioxide snow had lower TMA-N contents than in iced fillets. The differences observed in the rate of accumulation of TMA-N contents could be due to the differences in the growth of bacteria capable of reducing TMAO (Hebard *et.al.*, 1982).

Changes in hypoxanthine (Hx) content of black pomfrets stored in packages I, II and III are shown in Fig. 7. Initial Hx content of fresh fish was 3.46 mg/100g. On the 1 h, slight decrease in Hx content was observed in package II, whereas in packages I and III, it slightly increased. On further storage, Hx content increased gradually in all the three packages and reached to 8.96, 8.80 and 6.11 mg/100g in packages I, II and III, respectively at the end of the storage period. Perez-Villarreal & Pozo (1990) observed a linear increase in hypoxanthine content at a slow rate reaching 20 mg/100g at the end of storage period of ice stored albacore. Significant difference ($P < 0.05$) was observed in Hx contents of pomfrets stored in three different packages.

Changes in free fatty acid (FFA) content of black pomfrets stored in packages I, II and III are shown in Fig. 8. Initial FFA content was 33.93% as oleic acid. On the 1 h, it decreased to 10.96, 10.92 and 11.19% in packages I, II and III, respectively. The same was maintained on the 6 h in package III, but it decreased to 10.35% in package II. On further storage, it increased and attained a level of 21.46 and 21.91% in packages II and III, respectively. In package I, it reached 54.34 % at the end of the storage period. Changes in FFA content were found to be statistically significant ($P < 0.05$). It has been previously reported that emperor brems stored in dry ice exhibited the FFA content above 30% as oleic acid at the end of storage period (Jeyasekaran *et. al.*, 2004)

Temperature profile of black pomfrets stored in packages I, II and III are given in Table 2. Immediately after packaging, the temperatures recorded in packages I, II and III were 11.7, 13.2 and 10.6°C, respectively. At that time, room temperature was 33.4°C. Lowest temperature of -11.0°C was observed in package

I at the 5th h, which was maintained up to 6 h. However, sub-zero temperature was maintained even on the 15 h of storage in package I. LeBlanc & LeBlanc (1992b) observed a lowest temperature of -1°C when the haddock fillets were packed with 25% CO₂ snow. In packages II and III, the lowest temperatures recorded were 1.3 at 3 h and 8.0°C at 1 h of storage, respectively. After that, it increased gradually throughout the storage period. The results of present study confirmed the fact that the rate of deterioration/spoilage is highly temperature dependent (Sivertsvik *et. al.*, 2002).

Changes in gas composition of black pomfrets stored in package I, II and II are presented in Table 3. The atmospheric gas composition during this study was oxygen at 21.3%, carbon dioxide 0.5% and nitrogen 78.2%. After 1 h of packing, the oxygen, carbon dioxide and nitrogen content was 0.026%, 100% and 0% in package I, 0.034%, 100% and 0% in package II and 20.6%, and 1.2% and 78.2% in package III. Highest level of 100% CO₂ was noticed on the 1 h in the packages I and II, which was due to the packing of fish with dry ice. On the other hand, slight variation was observed in package III throughout the storage period. The longer shelf life obtained in dry ice packed steaks might be due to high content of CO₂ in such packages (Dhananjaya & Stroud 1994; Randell *et. al.*, 1999).

The results indicated that the storage of pomfrets stored in the combination of dry ice and ice increased the shelf life by about 50% in comparison with ice. Such package results in less transportation costs when exported by air to international markets thereby increasing foreign exchange earnings.

Authors thank the Indian Council of Agricultural Research (ICAR), New Delhi, Government of India for the financial assistance extended for carrying out this study. We are also grateful to the Dean, Fisheries College & Research Institute, Tamilnadu Veterinary and Animal Sciences University, Thoothukudi for having provided necessary facilities and support to carry out this study.

References

- APHA. (2001). *Compendium of methods for the microbiological examination of foods* (Speck, M.L., Ed), American Public Health Association, Washington DC, pp 25-35.
- Burt, J.R. (1976). *Hypoxanthine: a biochemical index of fish quality*. Torry memoir No. 538, Aberdeen, UK.
- Clark, D.S. and Lentz, C.P. (1969). The effect of carbon dioxide and growth of slime producing bacteria on fresh beef. *J. Can. Inst. Food Technol.* 2, pp72-75.
- Cobb, F., Alanoz, I. and Thompson, C. (1973). Biochemical and microbial studies on shrimp: volatile nitrogen and amine nitrogen analysis. *J. Food Sci.* 38, pp431-436.
- Dalgaard, P. (2000). *Freshness, quality and safety in seafoods*. FLAIR-FLOW, Europe Technical Manual F-FE 380A/00, Published by Teagase, The National Food Centre, Ireland.
- De la Hoz, L., Lopez-Galvez, D.E., Fernandez, M., Hierro, E. and Ordonez, J.A. (2000). Use of carbondioxide enriched atmospheres in the refrigerated storage (2°C) of salmon (*Salmo salar*) steaks. *Eur. Food. Res. Technol.* 210, pp179-188.
- Dhananjaya, S. and Stroud, G.D. (1994). Chemical and sensory changes in haddock and herring stored under modified atmosphere. *Int. J. Food Sci. Technol.* 29, pp575-583.
- Hebard, C.E., Flick, G.J. and Martin, R.E. (1982). Occurrence and significance of trimethylamine oxide and its derivatives in fish and shellfish. In: *Chemistry and Biochemistry of Marine Food Products* (Martin, R.E., Flick, G.J., Hebard, C.E. & Ward, D.R. Eds), AVI publishing Co., West port, USA. pp149-272.
- Huss, H.H. (1988). *Fresh fish: quality and quality changes*, FAO Fisheries Series, No. 29, Italy 132 p.
- Jay, J. (1987). *Modern food microbiology*, 1st Indian edn., CBS Publishers and Distributors, New Delhi, India. 642 p.

- Jayaweera, A.V., Villadsen, A., Desilva, T., Dealwis, D. and Jansen, M.A.B. (1980) Storage life of silver belly (*Lieognathus* sp.) with delayed icing. *Bull. Fish. Res. Stn.* **30**, pp53-61.
- Jeyasekaran, G., Ganesan, P., Jeya Shakila, R., Maheswari, K. and Sukumar, D. (2004). Dry ice as a novel chilling medium along with water ice for short-term preservation of fish emperor breams, lethrinus (*Lethrinus miniatus*). *J. Innovative Food Sci. Emerg. Technol.* **5**, pp485-493
- LeBlanc, R.J. and LeBlanc, E.L. (1992a). The effect of superchilling with CO₂ snow on the quality of commercially processed cod (*Gadus morhua*) and winter flounder (*Pseudopleuronectes americanus*) fillets. In: *Quality Assurance in the Fish Industry* (Huss, H.H., Jackobsen, M. & Liston, J. Eds), Elsevier Science Publishers B.V. pp115-124,
- LeBlanc, R.J. and LeBlanc E.L. (1992b). The effect of superchilling with CO₂ snow on the quality of commercially processed haddock (*Melanogrammus aeglefinus*) fillets. In: *Seafood Science and Technology* (Huss, H.H., Jackobsen, M. & Liston, J. Eds), Fishing News Books, London. pp 247-257.
- Lima dos Santos, C.A.M., James, D. and Teutscher, F. (1981). *Guidelines for chilled fish storage experiments*. FAO Fisheries Technical Paper No. 210. pp17-22.
- Pearson, D. (1968) Application of chemical methods for the assessment of beef quality. III. Methods related to fat spoilage. *J. Sci. Food Agric.* **19**, pp553-556.
- Perez-villarreal, B. and Pozo, R. (1990). Chemical composition and ice spoilage of albacore. *J. Food Sci.* **55**, pp678-682.
- Putro, S. (1989). Dry ice – possible uses in fresh and live fish handling. *INFOFISH Int.* **4**, pp24-25.
- Randell, K., Hattula, T., Skytta, E., Sivertsvik, M. and Bergslien, H. (1999). Quality of filleted salmon in various retail packages. *J. Food Quality.* **22**, pp483-497.
- Regenstein, J.M. and Regenstein, C.E. (1991). *Introduction to fish technology*, Van Nostrand Reinhold., New York. 87p.
- Sasi, M., Jeyasekaran, G., Shanmugam, S.A. and Jeya Shakila, R. (2000) Chilling fresh fish in dry and wet ice. *Asian Fish. Sci.* **13**, pp375-382.
- Sasi, M., Jeyasekaran, G., Shanmugam, S.A. and Jeya Shakila, R. (2003). Evaluation of the quality of seerfish (*Scomberomorus commersonii*) stored in dry ice (solid carbon dioxide). *J. Aqua. Food Prod. Technol.* **12**, pp61-72.
- Schoemaker, R. (1990). Shipping of fresh seafoods. *INFOFISH Int.* **4**, pp27-30.
- Scott, D.N., Fletcher, G.C. and Hogg, M.G. (1986). Storage of snapper fillets in modified atmospheres at -1°C. *Food Technol. Aus.* **38**, pp234-238.
- Sivertsvik, M., Jeksrud, W.K. and Rosnes, J.T. (2002). A review of modified atmosphere packaging of fish and fishery products – significance of microbial growth, activities and safety. *Int. J. Food Sci. Technol.* **37**, pp107-127.
- Stiles, M.E. (1991). Scientific principles of controlled/modified atmosphere packaging. In: *Modified Atmosphere Packaging of Food* (Ooraikul, B. & Stiles, M.E. Eds), Ellis Horwood, London. pp18-25.
- Surendran, P.K., Joseph, J., Shenoy, A., Perigreen, P.A., Iyer K.M. and Gopakumar, K. (1989). Studies on spoilage of commercially important tropical fishes under iced storage. *Fish Res.* **7**, pp1-9.
- USFDA (2001). *Bacteriological Analytical Manual*, 8th edn., Revision A, AOAC International, Gaithersburg, Md.