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ORIGINAL ARTICLE

Comparative evaluation of gum arabic coating and vacuum packaging on chilled storage characteristics of Indian mackerel (*Rastrelliger kanagurta*)

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Abstract The effect of edible coating using gum arabic on biochemical, microbiological, textural and sensory characteristics of fresh gutted mackerel stored at 4 °C was investigated. The results were further compared against the samples packed under vacuum (VP) and conventional polyethylene pouches (CP). Coating with gum arabic (GC) markedly retarded lipid oxidation process in gutted mackerel compared to VP and CP samples. Moreover, VP and CP samples showed higher degree of textural deterioration compared to GC samples. Microbiologically, the shelf life of chilled gutted Indian mackerel was estimated to be 7–8, 17 and 19–20 days for CP, GC and VP samples, respectively. The sensory analysis scores confirmed the efficacy of gum coating in retarding the spoilage process during chilled storage. The current study identifies the potential of edible coating with gum arabic to improve the overall quality of Indian mackerel and extend its storage life during chilled storage.

Highlights
- Tested efficacy of gum arabic coating against vacuum and polyethylene packaging for chilled Indian mackerel.
- Better protection against fat oxidation and textural changes in gum coated fish samples.
- Microbiologically vacuum and gum coating gave similar results, whereas gum coating samples had higher sensory score.

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Introduction

Vacuum packaging and modified atmospheric packaging are the common techniques employed for preservation of fatty fishes, which can act synergistically with lower temperature to retard the spoilage process during storage. Though these practices are found to be highly effective in enhancing the storage stability of muscle foods by 50–400 % when coupled with chilled storage, the major limitation is the outgrowth and toxin production by the non-proteolytic *Clostridium botulinum* type E (Blakistone 1998b). Hence, the safety of these products depends largely on the proper maintenance of cold chains (below 3.3 °C), as quite often these products are subjected to temperature abuse in retail outlets. The requirement of high barrier laminated packaging films, special machinery and technical expertise are other constraints.

Edible coating with a suitable film forming hydrocolloid is a comparatively cheaper technique, as it omits the requirement of high barrier packaging films, special packaging machinery or technical expertise. Gum polymers obtained from natural sources like seeds, tree exudates and microbes are considered as good agents for edible coating. Gums are used in small amounts in most product formulations, therefore they are cost effective. Gum arabic is the most popularly marketed gum and is in high demand both in the domestic as well as the International market. Moreover, it has received the highest toxicology safety status from the joint FAO/WHO Expert Committee on Food Additives. Apart from the protection against fat oxidation, it retards aerobic growth as the coating creates a reduced atmosphere inside the pack. This is because, coating

with gums causes closure of pores on the surface of the fish, thereby excluding the entry of air from the product surface. It also prevents moisture loss from fish surface as the moisture is lost from the coating prior to that from the tissue.

Edible coatings have widely been used for value added fishery products, but very rarely for whole fish. Indian mackerel (*Rastrelliger kanagurta*) is one of the most popular and commercially important pelagic fishes of India and neighbouring countries. The commercial use of fatty fish like Indian mackerel in fresh form is limited by its easy susceptibility to spoilage during processing and storage. The proportion of polyunsaturated fatty acids (PUFA) in Indian mackerel is approximately 47 % of total fatty acid content, and is highly prone to oxidative deterioration (Ganga et al. 2010). Hence, low storage temperature alone cannot aid its preservation. In fruits and vegetables, several researchers have reported significant extension of shelf life during chilled storage, when gum arabic was applied as edible coating (Jiang et al. 2013; Maqbool et al. 2011). However, very limited studies have been reported in fresh muscle foods on the protective effect of gum arabic during chilled storage. Previously, gum arabic coating containing garlic and cinnamon has been suggested as natural preservative for meat and fish under chilled storage (Rakshit and Ramalingam 2013). Recently, El-Sheikh (2014) has reported a 6 log reduction in total bacterial count by coating with 25 % gum arabic in boneless chicken breast stored at 4 °C. Therefore, the present study was aimed to evaluate the efficacy of gum arabic coating as an alternative to conventional and vacuum packaging technique on the compositional, microbiological, textural and sensory parameters of eviscerated Indian mackerel during chilled storage.

Materials and methods

Raw material

The freshly caught Indian mackerel (*Rastrelliger kanagurta*), having an average weight of 200 g and length of 18 cm were procured from the nearest fish landing centre, Vashi, India. Immediately after procuring, the fish were properly washed with potable water, iced and brought to the laboratory in insulated boxes. Further, the whole batch was assorted to three lots of uniform weight, after gutting and washing. Lot I was immediately packed in polyethylene pouches (250 gauge) (conventional polyethylene pack- hereafter designated as CP pack); lot II was vacuum-packed in laminated pouches (size: 15 × 22 cm; 12 μ-polyester laminated with 300 gauge low-density polyethylene) and sealed in a vacuum packaging machine (Model TTM 363708, Winner electronics, Mumbai, India) at 1 bar pressure (hereafter designated as VP pack); lot III was given a dip treatment for 10 min in chilled gum arabic solution (10 % *w/v*) at 1:2 ratio (fish: solution) and packed in polyethylene pouches after surface drying under chilled air (hereafter designated as GC pack). The coating solution was prepared by dissolving gum arabic in distilled water followed by heating at 40 °C for 30 min on a magnetic stirrer. The solution was filtered and cooled to 4 °C prior to coating. The concentration of gum arabic was determined based on preliminary trials with different concentrations of gum arabic solutions (5, 10, 15 and 20 %). The concentration of gum that yielded a transparent, firm and stable film on the surface of fish was selected for edible coating. All the three batches of samples were kept in chilled atmosphere maintained at 2 ± 2 °C. The samples from each batch were drawn regularly in triplicate for biochemical, microbiological, texture profile and sensory analyses. Initially, the sampling was carried out on alternate days. However, as the spoilage progressed, sampling was done on every subsequent day based on the value of spoilage indices obtained.

Biochemical analysis

Proximate composition of the raw fish meat was determined by AOAC (2002) method. pH of the homogenised sample in distilled water (1: 5 *w/v*) was determined by using a glass electrode digital pH meter (Cyberscan 510, Eutech instruments, Singapore). Drip loss of the fish during chilled storage was measured gravimetrically by taking the weight difference of the sample with and without exudate and expressed as ml of water/100 g fish meat. Total volatile base nitrogen (TVB-N), thiobarbituric acid (TBARS) value, peroxide value (PV) and free fatty acid (FFA) value were determined by the method detailed by Binsi et al. (2014).

Microbiological analysis

Microbiological analysis was carried out for total viable count (TVC), lactic acid bacteria (LAB), total *Enterobacteriaceae*, *Escherichia coli* (*E.coli*), lipolytic bacteria, H_2S forming bacteria as detailed previously (Binsi et al. 2015).

Texture profile analysis (TPA)

Texture profile analysis of all the samples were carried out in triplicate using Lloyds Texture Analyzer (Lloyd Instruments, Model LRX Plus, and U.K). Uniform areas identified on the middle section of the whole fish having similar shape and smooth surface were subject to a compression of 40 % with a trigger force of 0.5 kg. The results of TPA were tabulated using Nexygen software.

Sensory analysis

Sensory analysis of raw and cooked samples was conducted by a panel of 6 experienced members as explained previously by Binsi et al. (2015).

Statistical analysis

All the measurements were taken in triplicate and the data was subjected to Analysis of Variance (ANOVA) by SPSS. The mean ranking of overall acceptability of various samples at different storage days were compared by Friedman's analysis of variance. The significance of chi-square statistic was evaluated at 5 % level of significance.

Results and discussion

In the present study, a preliminary coating trial was carried out with gum arabic at 5, 10, 15 and 20 % (*w/v*) level. At lower concentration of 5 %, the edible film formed on the fish surface was too thin, which subsequently dissolved in the muscle tissue after few hours of storage under chilled condition. On the otherhand, 15 % and 20 % solutions yielded viscous solutions of dark brown colour, which formed a light brown coloured film on fish surface giving an inferior sensory appearance to the coated fish. At 10 % concentration, a stable colourless transparent film was formed on the surface, and hence selected for chilled storage study.

Proximate composition of fresh Indian mackerel

The average protein content of fresh mackerel meat was found to be 21.06 %. Based on the lipid content, mackerel can be classified as a medium fatty fish as the average fat content was about 3.29 %; hence, suitable for evaluating the efficacy of edible coating and vacuum packaging during chilled storage.

Biochemical changes during chilled storage

Moisture content

In general, the moisture content of all the samples presented comparable values during the initial 11 days of chilled storage, and thereafter GC samples exhibited significantly higher values ($p < 0.05$) (Fig. 1a). The VP samples presented slightly lower moisture content during the initial 3 days of storage, which may be attributed to the loss of moisture under vacuum through the minute capillaries present in the muscle. CP samples also showed gradually decreasing trend, indicating the possibilities of moisture loss from fish surface. The significantly higher moisture content observed in gum coated samples ($p < 0.05$) may be due to the absorption of moisture from the storage environment, as gum arabic is hydrophilic in nature (Tomasik 2003). Gum arabic is a natural mixture of hydrophilic carbohydrate and hydrophobic protein components, the hydrophilic part being the dominant one (FAO 1990).

Drip loss

A significantly higher drip loss was observed for GC samples as compared to VP and CP samples ($p < 0.05$) (Fig. 1b). However, this higher driploss observed in GC samples cannot be accounted as loss from fish samples, as higher moisture content was registered in the meat during chilled storage. The probable reason may be the penetration of moisture from the storage environment in to the package and further condensation, owing to the poor barrier properties of polyethylene packaging material. In GC samples, the maximum drip registered was 3.74 % on 3rd day of sampling and thereafter showed lower values. The drip loss is a technologically and economically important parameter for packaged muscle foods as it is a major attribute affecting the presentation of products. In the present study, the drip formed was not significant enough to affect the sensory appeal of the fish packed inside the pouch. Conversely, the drip imparted a glossy and moisturising effect for the fish surface during initial days of chilled storage in GC samples.

pH

In general, the pH values followed a distinctly different trend for all the three samples during chilled storage (Fig. 1c). pH

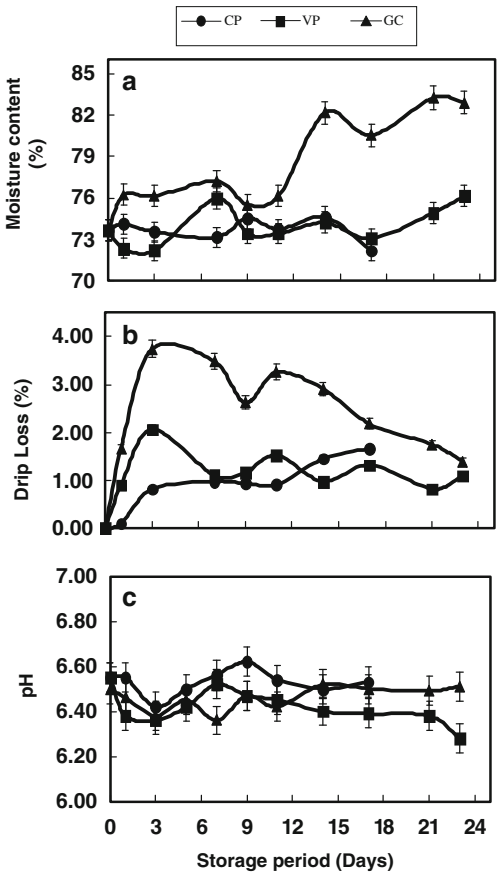

Fig. 1 Changes in **a** Moisture **b** Drip loss and **c** pH of Indian mackerel during chilled storage

remained consistently low during the initial 3 days in all the samples. During later period of chilled storage, CP samples showed gradually increasing values, whereas VP and GC samples showed fluctuating values. The mean pH values of CP samples were higher than that of VP and GC samples at any day of sampling, but not statistically significant ($p < 0.05$) (Fig 1a). The pH of fish meat at the time of packing was 6.5–6.55, which was increased to 6.68 in CP samples towards the end of storage period. It is obvious that pH increases during extended chill storage under aerobic conditions, due to the decomposition of amino compounds caused by microbial activity on amino acids and short peptides. On the contrary, GC and VP samples presented lower pH values towards the end of chilled storage, which may be due to the proliferation of glucose fermenting bacteria such as lactic acid bacteria (LAB), under reduced oxygen tension. Lactic acid bacteria ferment glucose and other substrates that are present in meat, lowering the pH of the environment (Gram and Huss 1996). The anoxic condition coupled with the lower pH of the fish muscle has a synergistic inhibitory effect on the growth of bacteria associated with fish spoilage. However, fish meat is not expected to acidify to a great extent by lactic acid generation, because fish muscle tissue contains very little glycogen (0.3 %) (Lakshmanan 2000). In our experiment, eventhough VP and GC samples showed a decreasing trend, pH values never dropped below 6.3. In the present study, pH of all the samples were well below 7 and the change in pH at the time of sensory rejection was less than 0.2 units.

Trimethyl amine (TMA) and total volatile base nitrogen (TVB-N)

The initial TMA content of mackerel was low (1.4 mg%) indicating the superior quality of the raw material used for the study (Fig. 2a). TMA increased linearly and significantly with storage time in all the samples ($p < 0.05$). The highest concentration of TMA was observed in CP samples, followed by GC and the lowest in VP sample. According to Teskeredzic and Pfeifer (1987). the offensive fishy odour occurs when the TMA concentration exceeds 10 mg%. In the present study CP samples crossed this limit on 11th day of storage, and both VP and GC samples on the 14th day. The TMA value of GC samples at any particular day of sampling was significantly higher than that of VP samples ($p < 0.05$).

The mean TVB-N content of fresh mackerel was 12.6 mg% which gradually increased towards the end of chilled storage period (Fig. 2b). All the samples followed similar trend till 7th day of storage, while showing significantly different values thereafter ($p < 0.05$). CP samples showed a sharp rise in TVB-N content on 9th day of storage, with the maximum value of 30.8 mg% on 14th day of sampling. On the other hand, VP and GC samples showed significantly lower values of TVB-N, well within the acceptable limit of 30 mg% throughout the

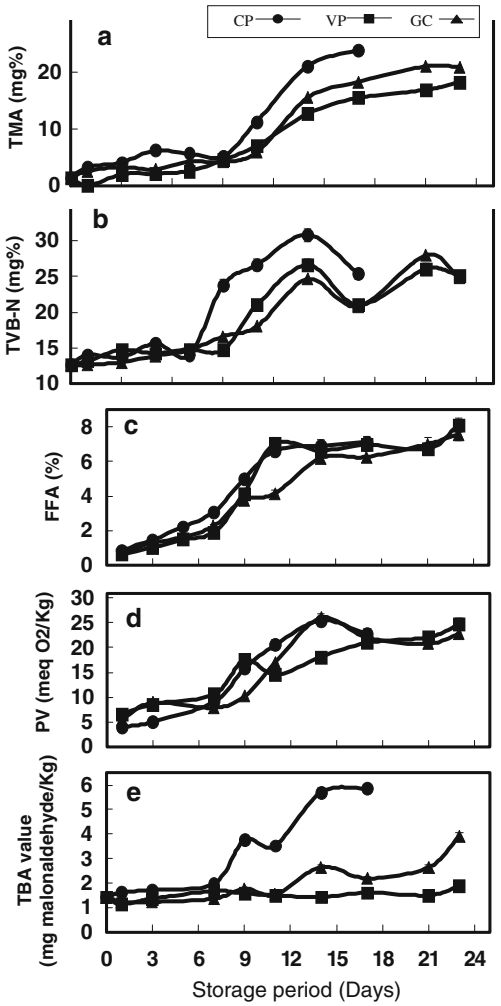

Fig. 2 Changes in **a** TMA **b** TVB-N **c** FFA **d** PV **e** TBA values of Indian mackerel during chilled storage

chilled storage period ($p < 0.05$). A TVB-N value of 35 mg% has been proposed as an upper acceptability limit for spoilage initiation in fresh fish by the European Commission (Commission of the European Community 1995). However, various authors have reported different acceptability levels for different fish species depending on specific treatments and processing conditions. For this reason, TVB-N is an appropriate quality index during advanced spoilage but is an insufficient sign of quality during the initial stages of seafood spoilage.

Free fatty acid value (FFA)

FFA values of all the samples showed a significant increase, except for GC sample which showed a significantly lower rate of FFA generation throughout chilled storage ($p < 0.05$) (Fig. 2c). The FFA values of VP samples were lower than that of CP and GC samples till the end of 7th day of chilled storage, and thereafter showed values similar to that of CP samples. It has been reported that during early period of chilled storage, FFA is mainly produced by the endogenous lipases

and phospholipases, and later on by microbial lipases (Auburg et al. 2010). Lipase, phospholipase A_2, and phospholipase B are believed to be the major endogenous enzymes associated with lipid hydrolysis in fish, while phospholipase C is derived mostly from microorganisms (Brockerhoff and Jensen 1974). Accordingly in the present study, the endogenous enzyme activity was negligible in all the samples as the values remained almost constant during the initial week of chilled storage. Later on, microbial activity became prominent after 5th day of chilled storage in CP and VP samples. In planktonivorous fish like oil sardine and mackerel seasonal changes in lipase activity is reported (Lopez-Amaya and Marangoni 2000). Moreover, activity of endogenous fish lipases is reported to be optimum at around pH 8 (Lopez-Amaya and Marangoni 2000). In the present study, slightly higher values were reported after 3rd day of chilled storage in VP and CP samples. In fish, endogenous lipase activity is mainly detected in muscle, gut and liver. Hence, evisceration along with retarding the growth of lipolytic bacteria can control lipid hydrolysis to certain extent.

Peroxide value (PV)

Lipoxygenase present in muscle, skin, gill and liver catalyses the incorporation of oxygen to cis-1,4 pentadiene in polyunsaturated fatty acids to form the hydroperoxide derivatives at a specific position, and is indicated by peroxide value. In the present study, the PV of fresh Indian mackerel was 2.34 meq of O_2/kg of fat, which increased linearly with storage time in all the three samples ($p < 0.05$) (Fig. 2d). Steadily increasing values were observed during 3–14, 7–9, and 9–14 days for CP, VP and GC samples, respectively. Generally, peroxide value of 20 meq O_2/kg of fat is considered necessary for oils to become rancid and the period to reach this value is considered as induction period (Hras et al. 2000). The results clearly show that GC and VP samples delayed the development of hydroperoxides significantly during initial period of chilled storage compared to CP samples as indicated by extended induction period, which was 11 days for CP, 14 and 17 days for GC and VP, respectively. This could be due to the limited availability of oxygen which is the major initiator of lipid peroxidation. The highest mean values of PV observed for all the samples during the chilled storage period were well above this established limit.

Thiobarbituric acid reactive substances (TBARS)

TBARS is a major indicator of secondary lipid oxidation which measures the amount of malonaldehyde formed as a result of oxidation of lipid hydroperoxides. The VP samples showed lower TBARS values throughout the chilled storage period (Fig. 2e). On the contrary, both CP and GC samples showed gradually increasing values of TBARS, eventhough GC samples presented significantly lower values compared to that of CP samples ($p < 0.05$). TBARS value in the range of 1–2 mg malonaldehyde/kg of fish sample is usually taken as the limit of acceptability (Lakshmanan 2000). beyond which fish will normally develop an objectionable odour and taste. Higher acceptability limit of 5–8 mg malonaldehyde/kg flesh for chill stored fish was reported previously by Nunes et al. (1992). The TBARS value of CP and GC samples remained below 2 mg malonaldehyde/kg till 7th and 11th day of chilled storage, respectively, and thereafter showed a sharp rise. On the other hand, TBARS values of VP were well below the given limit throughout the chilled storage period. High TBARS values are expected in fresh mackerel as compared to other lean fish species, due to high concentration of unsaturated fatty acids and pro-oxidants in the muscle of mackerel. The observed stability of the vacuum packed samples to lipid oxidation during chilled storage could be attributed to the removal of oxygen from the pack as well as the superior barrier properties of the packaging material. It has to be noted that, TBARS values may not always reflect the actual rate of lipid oxidation since malonaldehyde can interact with other components of fish muscle and thus making it unavailable for TBARS (Auburg 1993). However, once the value crosses the maximum limit of acceptability, it should be taken as a definite indication of fat deterioration. Results in the present study suggest that, gum coating delayed the progress of lipid oxidation considerably, however, not upto the extent of vacuum packaging.

Microbiological changes during chilled storage

Total viable count (TVC)

The fresh mackerel had a total viable count of 3.73 $\log_{10}$ cfu/g. During chilled storage, bacteria grew quickly in CP samples than in VP and GC samples (Fig. 3a). VP and GC samples showed overlapping curves, with closer values at any day of sampling. According to the prescribed microbial limit of acceptability in terms of total viable count which is 10^7 cfu/g (ICMSF 1986). the shelf life of CP sample was 7–8 days, 19–20 days for VP, and 17 days for GC samples. One of the major mechanisms of vacuum packaging and edible coating technique is the reduced oxygen tension in the food environment which has varying effect on the growth of different groups of microorganisms. The low bacterial count observed in VP and GC samples may be attributed to the immediate effect of reduced partial pressure of O_2 in the package environment. In the present study, the general trend in TVC of all the samples indicated a positive correlation with TVB-N content of the samples, with highest for VP samples ($R^2 = 0.81$). This was expected, as TVB-N is a product of both autolytic and bacterial degradation. On the otherhand, all the three samples showed a poor correlation with pH (R^2 = less than 0.25).

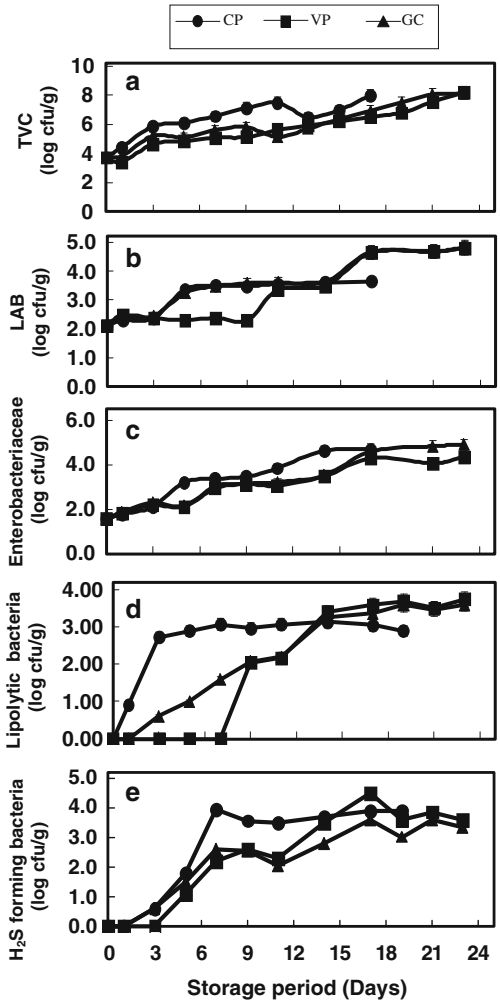

Fig. 3 Changes in the count of **a** TVC **b** LAB **c** enterobacteriaceae **d** lipolytic bacteria **e** H_2S forming bacteria of Indian mackerel during chilled storage

Hence, pH was found to be an unreliable quality indicator in Indian mackerel during chilled storage.

Lactic acid bacteria (LAB)

TVC alone cannot be considered as a suitable index to determine the shelf life and deterioration of fish. This is because, the growth of Gram negative facultative anaerobes will be inhibited, if there is considerable growth of interfering organisms like lactic acid bacteria (LAB). LAB produces natural preservatives such as short-chain fatty acids and bacteriocins that lower the pH of the media and protect against pathological changes in fish during storage. In the present study, lactic acid bacteria showed a slow and gradual growth throughout the storage period (Fig. 3b). This was expected, since LAB tends to grow slowly at refrigeration temperatures (Huisin't and Jos, 1996). The LAB count of GC and CP samples presented similar growth pattern throughout chilled storage period, with a steep increase on 5th day of sampling, and thereafter remained almost constant from 7th to 14th day of storage. For VP samples however, the growth was at a still lower rate with a definite plateau region till 9th day of storage, followed by slightly higher values in the subsequent days. Generally, LAB thrives well under anaerobic and microaerophilic conditions that exist in vacuum packed food stuffs. In the present study also, irrespective of the treatment, the growth of LAB during chilled storage was not significant enough to bring down the pH of the system and to deliver any protective effect over other spoilage causing organisms ($p < 0.05$).

Enterobacteriaceae and E. coli

Enterobacteriaceae can survive in microaerophilic conditions and develop unpleasant odours or discolouration in products packed under reduced oxygen atmosphere. Edible coating also creates a microaerophilic condition by forming a barrier film over the product surface. Hence, the enumeration of these microorganisms is important in edible coated and vacuum packed products. The low initial count of Enterobacteriaceae observed in fresh gutted mackerel (1.57 $\log_{10}$ cfu/g) indicates the adequacy of hygiene handling practices followed during gutting and packaging of fish samples (Fig. 3c). The Enterobacteriaceae count of all the samples presented similar values till 3rd day of chilled storage, indicating that vacuum packing and coating treatments were carried out without any time and temperature abuse. However, from 5th day onwards, CP samples showed significantly higher values of Enterobacteriaceae count than VP and GC samples ($p < 0.05$). Between the treatments, VP samples presented lower values compared to GC samples; even though statistically not significant till 14th day of storage, the difference became significant thereafter ($p < 0.05$). The lower count of Enterobacteriaceae observed in VP samples may be due to the synergistic effect of cold shock and immediate removal of O_2 from the pack environment.

Escherichia coli was not detected in any of the samples throughout chilled storage period. This indicates that the flesh was not contaminated with gut content of fish during evisceration and cleaning process. Besides, this also indicates the good handling practices followed in landing centre and during transportation of raw material to the laboratory.

Lipolytic bacteria

Lipolytic bacteria produce lipases, that catalyses the hydrolysis of fats to free fatty acids and glycerol, which in turn gives better accessibility for oxygen molecule to unsaturated fatty acids and makes them extremely susceptible to mechanisms involved in lipid damage. In the present study, the three samples presented distinctly different lipolytic bacterial growth pattern during chilled storage (Fig. 3d). The lipolytic count of CP samples were significantly higher than that of VP and

GC samples, with a sharp peak on 3rd day of chilled storage ($p < 0.05$). The lipolytic bacterial growth was not evident in VP samples till 7th day of storage, whereas GC samples showed its presence from 3rd day onwards. In the present study, good correlation between lipolytic counts and FFA was obtained for GC ($R^2 = 0.98$) and VP samples (R^2=0.95), whereas poor correlation was observed for CP samples ($R^2 = 0.49$). This implies that, in CP samples the intrinsic lipolytic enzymes were also active in hydrolysing the lipid, apart from the lipolytic bacteria.

H_2S forming bacteria

The spoilage of chilled fish is associated with the liberation of a number of metabolic gases such as H_2S, produced mainly from sulphur containing amino acids. In the present study, CP and GC samples showed the presence of H_2S forming bacteria from 3rd day onwards, whereas, VP samples indicated the presence from 5th day onwards (Fig. 3e). The CP sample showed the highest count of H_2S formers on 7th day followed by gradually decreasing values till the end of storage. Among the three samples, VP showed the lowest count during initial 7 days of storage, and thereafter GC samples excelled. Moderate correlation was observed between growth of H_2S formers of all the samples and TVB-N values over chilled storage period ($R^2 = 0.56$), whereas a poor correlation was observed with pH ($R^2 = 0.38$). Even though, most of the H_2S formers are obligate or facultative anaerobes, the count was significantly higher in CP samples compared to VP and GC samples, during initial stages of chilled storage. This is because, these volatile metabolites are generally formed after certain proteolysis has occurred, giving rise to smaller peptides and free amino acids, delivering better access to the sulphur containing aminoacids. This implies that, proteolysis occurred at a faster rate during chilled storage in CP samples as also confirmed by TVB-N value, which was delayed in the case of VP and GC samples.

Pseudomonas spp.

The growth pattern of *Pseudomonas spp.* during chilled storage was similar for all the samples during initial 3 days, thereafter showing distinctly higher values for CP and GC samples ($p < 0.05$) (Fig. 4a). The lower count exhibited by VP samples during chilled storage may be related to the unavailability of sufficient oxygen in the pack environment, as *Pseudomonas* is an aerobic bacteria. GC samples also showed retarded growth after 7 days of chilled storage, probably due to the exhaustion of residual air present in the pack. In the present study, the higher count of *Pseudomonas* spp. detected on 11th day of chilled storage coincided with the generation of off-flavor in CP samples as confirmed by sensory evaluation.

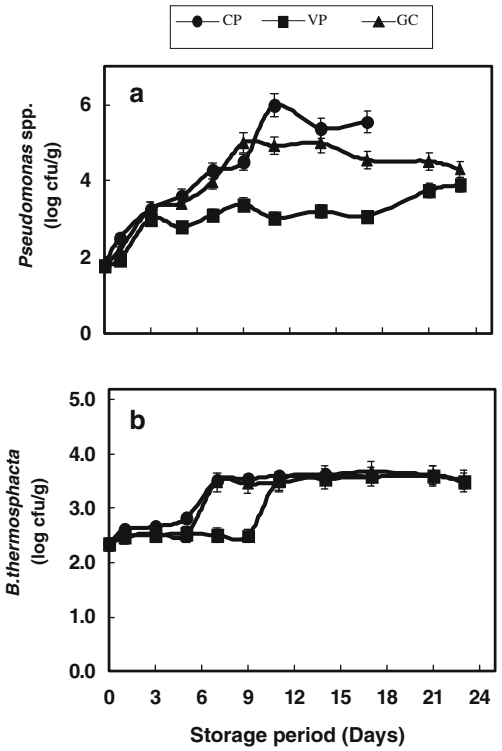

Fig. 4 Changes in **a** *Pseudomonas spp.* **b** *B.thermosphacta* counts of Indian mackerel during chilled storage

Brochothrix thermosphacta

B. thermosphacta is considered as the predominant spoilage organism of vacuum packaged and modified atmosphere packaged meat (Pin et al. 2002). In the present study, the CP and GC samples presented similar values throughout the storage period, with a sharp rise in count from 7th day onwards and the value remained on the higher side till the end of chilled storage (Fig. 4b). On the other hand, VP samples showed consistently lower count till 9th day of storage and thereafter presented similar counts of CP and GC samples. The aerobic metabolism of *B.thermosphacta* is more offensive than the anaerobic metabolism, as in the presence of oxygen, the main products are acetoin and diacetyl, which are present in some cheeses and cause sweet odours (Pin et al. 2002). Under anaerobic/reduced oxygen atmosphere, as that prevails in vacuum packed and edible coated samples, glucose is metabolized by this organism mainly into lactic acid and ethanol. Hence, *B. thermosphacta* may become the dominant spoilage species when oxygen is present, but is displaced by *Lactobacillus* species under anaerobic conditions, and the concentration of undissociated lactic acid being the governing factor (Grau 1980). In the present study, slight retardation in the growth *B.thermosphacta* was observed in VP samples. However, no inhibitory effect was evident in CP or GC samples, probably because the concentration of lactic acid produced may not be sufficient enough to impose an inhibitory

effect on the growth of *B. thermosphacta*, as reflected in the count of LAB in GC and CP samples.

Texture profile analysis (TPA)

Some authors have recommended that TPA of raw fish should be performed on a fillet or a part of a fillet (Stejskal et al. 2011). However, in the present study, TPA was carried out on whole mackerel, as mackerel is a relatively a small sized fish, filleting may disturb muscle structure and may introduce considerable errors in analysis.

In general, the highest values were recorded by GC samples, closely followed by VP samples for all the parameters analysed. All the samples showed a moderate to high negative correlation with days of chilled storage for all the textural properties analysed (Fig. 5). The highest correlation for hardness values was observed for VP samples (−0.86) with almost similar value for GC samples. The initial increase in hardness values observed in all the samples during the 1st day of storage may be due to the immediate effect of chilling, resulting in restructuring of water and protein molecules (Fig 5a). CP samples showed highest reduction in hardness values during chilled storage, to the extent of 43 % by 3rd day of storage. On

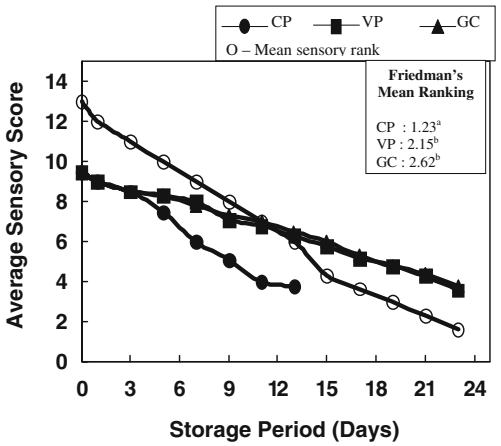

Fig. 6 Average overall sensory acceptability scores of Indian mackerel during chilled storage. Treatment mean values with same letters are not significantly different from each other ($p < 0.05$)

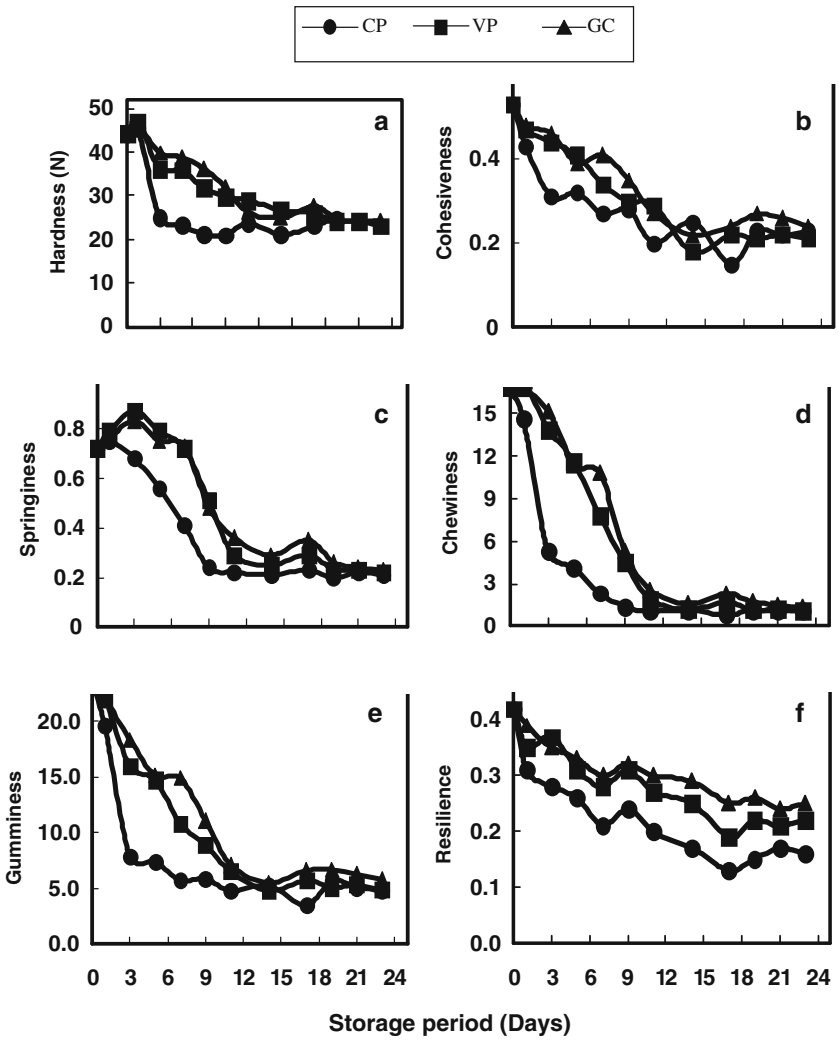

Fig. 5 Changes in **a** Hardness **b** Cohesiveness **c** Springiness **d** Chewiness **e** Gumminess **f** Resilience values of Indian mackerel during chilled storage

the contrary, VP and GC samples retained the original hardness to the maximum extent giving a value of about 44 % even at the end of the storage period. The reduction in hardness values with progress of chilled storage is expected, as spoilage process results in structural protein disintegration imparting more fluidity to the flesh under an external force.

Cohesiveness is the ratio of the area of force curve under the first and second compressions, which is the amount of deformation of the food before it is disjoint (Cheret et al. 2005). As the value is closer to 1, the object has more elastic properties. Generally, consumers prefer firm and elastic fish flesh. In the present study, the cohesiveness of fresh Indian mackerel was 0.53, which was drastically reduced to 0.27 on 7th day of storage in CP samples (Fig. 5b). The GC and VP samples also showed high negative correlation (−0.95) with storage period reaching one third of the original cohesiveness value by 14th day of chilled storage. Springiness, chewiness and gumminess values registered significantly lower values for CP samples compared to GC and VP samples, till 11th day of chilled storage, thereafter showing almost similar values. On the contrary, resilience values of GC and VP samples showed minimum difference till 5th day, thereafter showing significantly higher values for GC samples compared to VP samples (Fig. 5f).

The reduction in textural properties observed during the chilled storage may be related to the consequence of weakened connective tissue and the Z-lines that might be considerably disintegrated after storage (Lakshmanan 2000). From the results of TPA analysis, it was concluded that gum coating and vacuum packing offered better protection to Indian mackerel upto 11 days of chilled storage compared to conventional packing, and thereafter the difference between the samples were minimum. Further, edible coating with gum arabic was helpful in maintaining better textural integrity and elastic properties compared to vacuum packaging. This may be due to the enhanced water holding capacity of gum coated samples, thereby reducing the product shrinkage by preventing water loss.

Sensory evaluation

Even though CP samples crossed the limit of microbiological count, study was continued till the samples were rejected by the all the sensory panellists. Changes in the overall acceptability score based on appearance, colour, odour and flavour are presented in Fig. 6. The sensory deterioration was delayed in VP and GC samples compared to CP samples. Sensory deterioration was rapid in CP samples as evident by the development of off-odours, discoloration of skin and softening of the muscle. The fresh samples of Indian mackerel were bright silvery in colour with distinguishable black spots and shiny transparent slime over the skin. This characteristic appearance was well retained in GC samples compared to CP and VP samples during chilled storage. This may be explained on the basis of enhanced moisturising effect of gum coating on the mackerel samples. The samples behaved more or less similar during the initial 3 days of storage. As the chilled storage progressed, development of a brown band was evident along the lateral line coupled with intensification of off-odour. It was interesting to note that, the characteristic fishy flavour was less intense in VP samples, even during the first week of chilled storage. A sensory score of 4 was considered to be the borderline of acceptability. Accordingly, the sensory panellists rejected CP samples on 11th day of chilled storage. On the other hand, VP and GC samples showed almost similar spoilage pattern with slightly better score for GC samples, and were acceptable till 23 days of storage. The correlation analysis of TVC and sensory scores during chilled storage indicated a high negative correlation for GC samples ($R^2 = -0.94$), whereas CP and VP showed slightly lower correlation coefficient. As per statistical ranking, GC samples ranked the highest, followed closely by VP and CP samples at any time-point during chilled storage (Fig. 6, inset).

Conclusion

The quality of Indian mackerel under chilled storage was predicted based on the cumulative observations of biochemical, microbiological, textural and sensory parameters. Although, the sensory parameters showed enhanced shelf life by 4–6 days for all the samples, emphasis was given to microbiological safety rather than the progress of spoilage indicated by sensory analysis. Accordingly, the shelf life of Indian mackerel packed under conventional PE pouches was estimated to be 7–8 days. At the same time, GC and VP samples showed extended acceptability till 17 and 19–20 days, respectively under similar storage condition. Even though, VP samples showed lowest microbial growth among the three samples, the extension of microbiological shelf life was marginal over GC samples. Moreover, GC samples excelled in sensory evaluation. Hence, the results of the present study suggest the use of edible coating with gum arabic as an equally effective option against the costly vacuum packaging technique, for controlling the spoilage process in Indian mackerel during chilled storage.

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