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# Rheological characteristics of suwari and kamaboko gels made of surimi from Indian major carps

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**Abstract: The gel strength, compressibility and folding characteristic of suwari (set) and kamaboko (set and cooked) gels prepared from rohu (*Labeo rohita*), catla (*Catla catla*) and mrigal (*Cirrhinus mrigala*) surimi were examined to understand the occurrence of suwari and modori phenomena in surimi from major freshwater carps. Suwari setting of gels did not take place at lower temperatures. Suwari gels showed good gel strength at 50 °C for rohu and at 60 °C for catla and mrigal after 30 min setting time. Incubation for 60 min decreased the gel strength at 60 °C for rohu and catla. Setting at 25 °C followed by cooking at 90 °C increased the gel strength. Increased setting temperature, however, decreased the gel strength of cooked gels. Gel strength and compressibility data were supported by folding characteristics.**


**Keywords:** surimi; major Indian carps; suwari; kamaboko; gel strength; compressibility; folding characteristics

## INTRODUCTION

The Indian major carps (*Labeo rohita, Catla catla* and *Cirrhinus mrigala*) have been found to have good potential for utilisation for surimi production.[1] The conformational state of myosin, the essential component contributing to the elasticity of fish gels, is the most important factor in the development of the gel network.[2] The interaction between protein and water plays an important role in the conversion of sol to gel.[3] Besides, the gelling capacity of fish meat is species-dependent and is attributed to differences in the cross-linking of myosin heavy chains, to differences in the surface hydrophobicity of the unfolded domain of the myosin heavy chain and to the heating temperature.[4] The gels are formed when partially unfolded proteins develop uncoiled polypeptide segments that interact at specific points to form a three-dimensional cross-linked network. The strength of the gel increases with protein concentration, and the concentration of protein required depends on the protein properties.[3,5–7]

Gelation at low temperature (30–40 °C) takes place as a result of interactions among the tail portions of the myosin molecule[8] and owing to the action of certain transglutaminases through disulphide and covalent bonds.[9] At higher temperatures the interactions among the hydrophobic amino acids exposed as a result of protein unfolding at the myosin head portion contribute stability to the gels formed.[8] At temperatures above 80 °C, intermolecular disulphide bonds and more extensive intermolecular hydrophobic attractions are involved.[10] One-step heating at higher temperatures gave good gel strength in chum salmon,[11] while low-temperature setting followed by high-temperature cooking provided good gel strength in herring,[12] red hake[13] and Alaska pollock[13] surimi. Suwari (low-temperature setting) and modori (high-temperature degradation) are the two phenomena affecting the formation of the gel network[14,15] and are species-dependent.[16–18]

In this work an attempt has been made to study the rheological characteristics of gels from major carp surimi as a function of setting temperature and duration and cooking temperature and duration with a view to understanding the suwari and modori phenomena in major carp gels.

## MATERIALS AND METHODS

Fish (*Labeo rohita, Catla catla* and *Cirrhinus mrigala*) caught in prime condition from a freshwater pond were brought to the laboratory partially iced and kept overnight to resolve rigor. The post-rigor fish were washed thoroughly and used for the preparation of surimi (Fig 1). Sucrose (40 g $kg^{-1}$), sorbitol (40 g $kg^{-1}$) and tripolyphosphate (2 g $kg^{-1}$) were added as cryoprotectants. The packed surimi was frozen at −40 °C and stored at −20 °C until analysis.

### Preparation of heat-induced gels

Heat-induced gels were prepared from both mince and

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surimi by grinding the myofibrillar protein concentrate or surimi with 30 g $kg^{-1}$ NaCl for 3 min using a kitchen mixer. During grinding, the temperature of the surimi gel was kept below 10 °C to preserve the functionality of actomyosin.[19] The resulting paste was stuffed manually into polypropylene tubing of 5.0 cm diameter, taking care to eliminate the trapped air as much as possible.

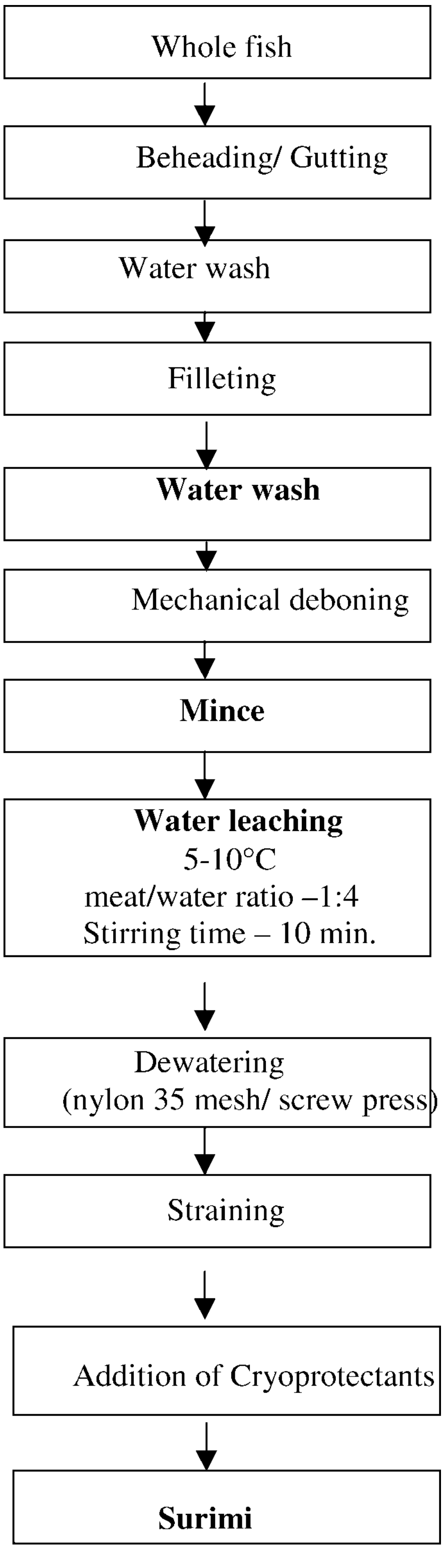


**Figure 1.** Scheme for processing Indian major carps for surimi preparation.

The packed gels were divided into two sets. Both sets were subjected to setting at 25, 35, 40, 50 or 60 °C for 30 or 60 min. One set was subjected to cooking at 90 °C for 30 min after setting. Both uncooked (suwari) and cooked (kamaboko) gels were cooled in ice and stored at 5 °C overnight before analysis.

### Rheological characteristics of gels

The *folding* characteristic was determined at 25 °C on gel samples 3 mm thick.[19] The maximum score (FT: A) indicated that no cracks were observed when the slice was folded twice without breaking. The minimum score (FT: D) was assigned if the slice broke into fragments when folded in half. The gel strength and compressibility were measured by a 'SUN' rheometer using cylindrical specimens 25 mm long and 37 mm in diameter and a 5 mm diameter plunger with a round head.[19] The *gel strength* (g cm) is defined as the product of breaking force (load (g)) and deformation (cm). The *compressibility* is defined as the force (g) required to compress the sample by a known distance (4 mm).

## RESULTS

### Rohu

Suwari gels set for 30 min showed only a slight (46–57 g cm) increase in gel strength up to 40 °C but two- and threefold increases on incubating at 50 and 60 °C (118 and 185 g cm respectively) (Fig 2). For gels set for 60 min the gel strength peaked at 50 °C (164 g cm) and then decreased at 60 °C (124 g cm) (Fig 2). The suwari gels did not set at 25 °C (Table 1) but formed a sticky mass with relatively poor rheological properties. Suwari gels showed good folding characteristics at 50 and 60 °C irrespective of setting time (30 or 60 min), but at 70 °C the gel strength decreased and consequently the folding characteristic deteriorated.

In the case of set and cooked gels, maximum gel strength was found with the gel set at 25 °C for 30 min (Fig 2). The gel strength decreased up to 40 °C and then increased again up to 60 °C. Increased duration of setting had a positive effect on gel strength at 40 and 50 °C but not at 60 °C.

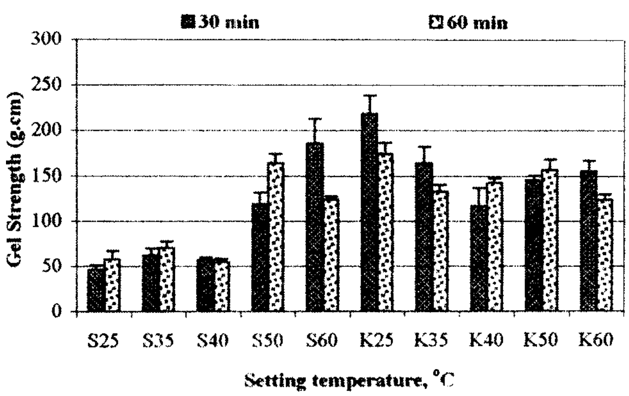


**Figure 2.** Gel strength of rohu suwari (S) and kamaboko (K) gels prepared at different setting temperatures and times.

Table 1. Folding test characteristics of heat-induced gels from rohu

| Temperature/time schedule (°C/min) | Folding test grade[a] | Characteristic |
|---|---|---|
| 25/30 | Not set | Soft and sticky |
| 25/30; 90/30 | Not set | Soft, not sticky |
| 25/60 | Not set | Soft and sticky |
| 25/60; 90/30 | B | Breaks on 2nd fold; soft, not sticky |
| 35/30 | B | Breaks on 2nd fold; soft and sticky |
| 35/30; 90/30 | A | Breaks on 2nd fold; soft and moderately firm |
| 35/60 | B | Breaks on 2nd fold; soft and sticky |
| 35/60; 90/30 | A | Breaks on 2nd fold; soft and moderately firm |
| 40/30 | A | Breaks on 2nd fold |
| 40/30; 90/30 | A | Breaks on 2nd fold very slowly |
| 40/60 | A | Breaks on 2nd fold |
| 40/60; 90/30 | A | Breaks on 2nd fold very slowly |
| 50/30 | AA | Soft, firm, chewable |
| 50/30; 90/30 | AA | Soft, firm, chewable |
| 50/60 | AA | Soft, firm, chewable; more elastic |
| 50/60; 90/30 | AA | Soft, firm, chewable; more elastic |
| 60/30 | AA | Soft, firm, chewable |
| 60/30; 90/30 | AA | Soft, firm, chewable |
| 60/60 | AA | Soft, firm, chewable; more elastic |
| 60/60; 90/30 | AA | Soft, firm, chewable; more elastic |
| 70/30 | A | Breaks on 2nd fold; soft and less elastic |
| 70/30; 90/30 | B | Breaks on 1st fold; soft and less elastic |

[a] AA, no crack occurs after folding twice; A, crack occurs after folding twice, but no crack occurs after folding once; B, crack occurs gradually after folding once.

The compressibility (Fig 3) of the suwari set gels was low at 25, 35 and 40 °C irrespective of duration of incubation, but increased with temperature. Higher compressibility values were found at 50 and 60 °C. The compressibility of cooked gels increased more than fourfold at 25 °C for both setting periods (30 and 60 min) compared to uncooked gels, but there was not much change with temperature.

## Mrigal

The pattern of setting followed almost the same trend as seen in the case of rohu. In suwari gels set for 30 min the gel strength (Fig 4) showed no increase up to 40 °C but increased on incubating at 50 and 60 °C. Increased setting time (60 min) increased the gel strength at 50 °C but decreased the gel strength at 60 °C. This can be interpreted as the appearance of the modori phenomenon at 60 °C after longer incubation (60 min). The suwari gels did not set at 25 °C (Table 2) but formed a sticky mass with relatively low compressibility (Fig 5) even with the longer time of setting. Slow setting was found at 30 and 40 °C. Only gels set at 50 or 60 °C irrespective of setting time (30 or 60 min) showed good folding properties with good elasticity.

In the case of cooked gels, maximum gel strength was found for the gel set at 25 °C for 30 min (Fig 4). The gel strength decreased with increasing temperature and duration of setting up to 50 °C.

The compressibility of suwari gels, as in the case of rohu, showed low values but increased with temperature and duration of setting up to 60 °C (Fig 5). In the

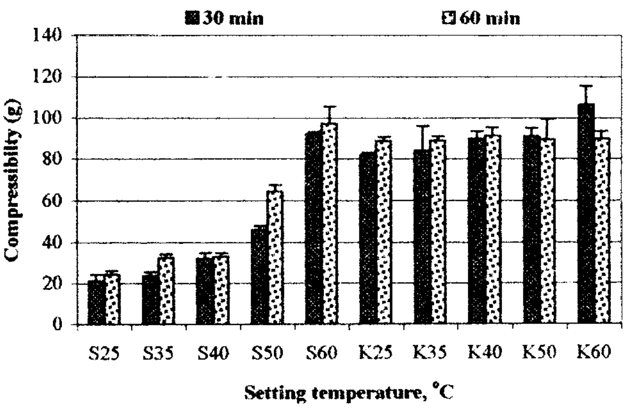


Figure 3. Compressibility of rohu suwari (S) and kamaboko (K) gels prepared at different setting temperatures and times.

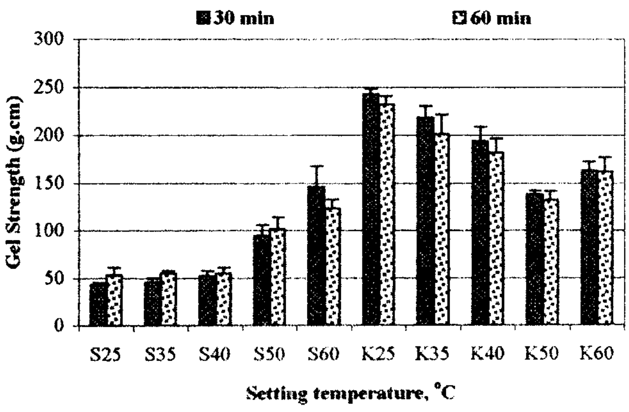


Figure 4. Gel strength of mrigal suwari (S) and kamaboko (K) gels prepared at different setting temperatures and times.

| Temperature/time schedule (°C/min) | Folding test grade[a] | Characteristic |
|---|---|---|
| 25/30 | Not set | Soft and sticky |
| 25/30; 90/30 | Not set | Breaks on folding; soft and sticky |
| 25/60 | Not set | Soft and sticky |
| 25/60; 90/30 | B | Breaks on 2nd fold; soft and sticky |
| 35/30 | B | Breaks on folding; soft and sticky |
| 35/30; 90/30 | A | Breaks on 2nd folding; soft and moderately firm |
| 35/60 | B | Breaks on folding; soft and sticky |
| 35/60; 90/30 | A | Breaks on 2nd fold; soft and moderately firm |
| 40/30 | A | Breaks on 2nd fold |
| 40/30; 90/30 | A | Breaks on 2nd fold very slowly |
| 40/60 | A | Breaks on 2nd fold |
| 40/60; 90/30 | A | Breaks on 2nd fold very slowly |
| 50/30 | AA | Soft, firm, chewable |
| 50/30; 90/30 | AA | Soft, firm, chewable |
| 50/60 | AA | Soft, firm, chewable; more elastic |
| 50/60; 90/30 | AA | Soft, firm, chewable; more elastic |
| 60/30 | AA | Soft, firm, chewable; more elastic |
| 60/30; 90/30 | AA | Soft, firm, chewable; more elastic |
| 60/60 | AA | Soft, firm, chewable; more elastic |
| 60/60; 90/30 | AA | Soft, firm, chewable; more elastic |

[a] See Table 1.

**Table 2.** Folding test characteristics of heat-induced gels from mrigal

case of cooked gels there was a 2.5-fold increase in compressibility at 25 °C for both setting periods and a further increase with temperature and duration of setting.

## Catla

The gel strength did not show any increase up to 40 °C but increased on further increase in temperature (Fig 6). In contrast to the decrease in gel strength found with increase in setting time (60 min) at higher temperatures for rohu and mrigal, catla showed increased gel strength with longer setting time. The folding test results showed good elasticity for gels set even at 40 °C, unlike the other two cases, and the maximum folding characteristic was found above 50 °C (Table 3).

In the case of set and cooked gels, maximum gel strength was found with the gel set at 25 °C for 30 min (Fig 6). The gel strength decreased with further increase in setting temperature up to 35 °C and then slowly increased. Similar results were found in the case of gels set for 60 min.

The compressibility of the suwari set gels increased with both temperature and duration of setting up to 40 °C, except for the gels set for 30 min above 40 °C (Fig 7). In the case of cooked gels the compressibility of the gels set for 30 min increased with temperature up to 40 °C and then decreased. The longer setting time (60 min) also produced a similar pattern, but the decrease started at 35 °C, as opposed to rohu and mrigal.

## DISCUSSION

For most marine fish, setting at lower temperature, especially at 40 °C, prior to cooking at 90 °C produces a gel of greater strength than that obtained by cooking

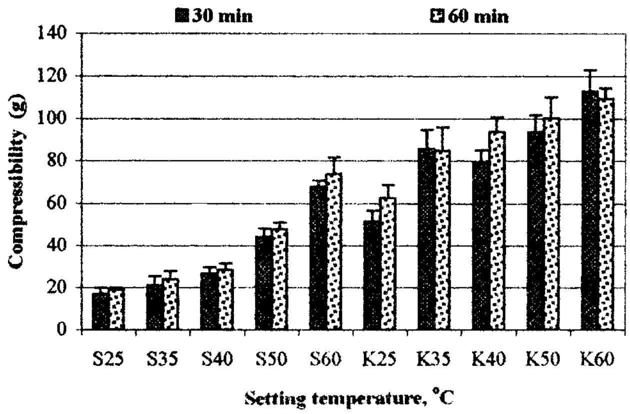


**Figure 5.** Compressibility of mrigal suwari (S) and kamaboko (K) gels prepared at different setting temperatures and times.

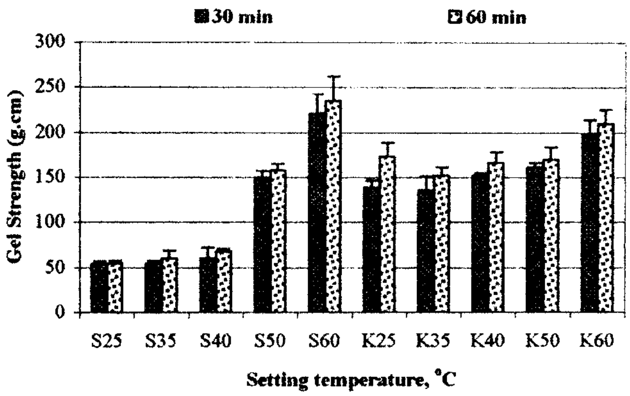


**Figure 6.** Gel strength of catla suwari (S) and kamaboko (K) gels prepared at different setting temperatures and times.

**Table 3.** Folding test characteristics of heat-induced gels from catla

| *Temperature/time schedule (°C/min)* | *Folding test grade[a]* | *Characteristic* |
|---|---|---|
| 25/30 | Not set | Soft and sticky |
| 25/30; 90/30 | AA | Soft not sticky |
| 25/60 | Not set | Soft and sticky |
| 25/60; 90/30 | AA | Soft, not sticky |
| 35/30 | Not set | Breaks on folding; soft and sticky |
| 35/30; 90/30 | AA | Soft and moderately firm |
| 35/60 | Not set | Breaks on 1st fold; soft and sticky |
| 35/60; 90/30 | AA | Soft and moderately firm |
| 40/30 | B | Bends but breaks on 1st fold |
| 40/30; 90/30 | AA | Soft, firm, crisp, chewable and elastic |
| 40/60 | AA | Soft, firm, crisp, chewable and elastic |
| 40/60; 90/30 | AA | Soft, firm, crisp, chewable and elastic |
| 50/30 | AA | Soft, firm, crisp, chewable and elastic |
| 50/30; 90/30 | AA | Soft, firm, crisp, chewable and elastic |
| 50/60 | AA | Soft, firm, crisp, chewable and elastic |
| 50/60; 90/30 | AA | Soft, firm, crisp, chewable and elastic |
| 60/30 | AA | Soft, firm, crisp, chewable and elastic |
| 60/30; 90/30 | AA | Soft, firm, crisp, chewable and elastic |
| 60/60 | AA | Soft, firm, crisp, chewable and elastic |
| 60/60; 90/30 | AA | Soft, firm, crisp, chewable and elastic |

[a] See Table 1.

at 90 °C without pre-incubation.[20] The formation of translucent gel from salt-solubilised myofibrillar protein takes place at a temperature which is optimal for partial unfolding of the protein structure.[3] Setting of fish proteins at temperatures below 40 °C takes place when the partially denatured proteins interact non-covalently and form an elastic network,[21] and subsequent cooking at 90 °C results in a stronger and more elastic gel.[22–25]

Setting at higher temperature is related to the transition in rheological properties, while low-temperature setting is related to the action of transglutaminase enzymes.[8,26] There was no setting on incubating at lower temperatures (25, 35 and 40 °C) in rohu, catla and mrigal, and this appears to indicate that at lower temperatures the actomyosin from these fish does not unfold to the extent required to bring about the cross-linkages that will facilitate the development of the gel network. The unfolding of native myosin in rohu, catla and mrigal takes place at temperatures above 40 °C, and the interactions among the exposed groups lead to the increased gel strength at these temperatures.[1] This may be related to the stability of actomyosin at lower temperatures in these species and also to the possibility of either the absence or low activity of transglutaminase in major carp muscles. A similar type of non-setting of salted salmon paste at 25 and 40 °C has been reported and related to the absence of factors responsible for gel setting in salmon flesh.[27] Surimi from sardine showed poor gel formation at 25 °C and required a longer setting time.[28] It has also been reported that the gel-forming ability of muscle proteins from poor-setting fish can be enhanced by combining them with those from good-setting fish at appropriate temperatures of unfolding of the protein chain.[29]

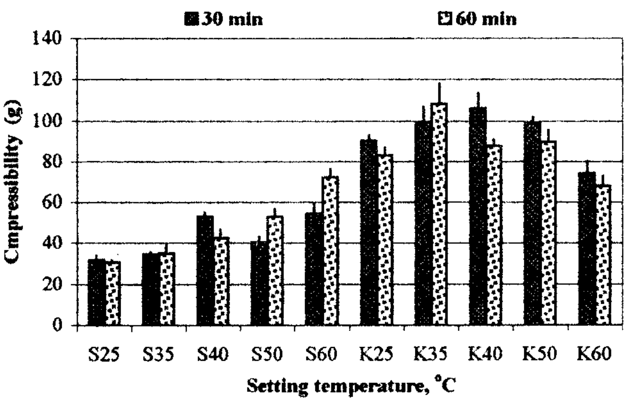


**Figure 7.** Compressibility of catla suwari (S) and kamaboko (K) gels prepared at different setting temperatures and times.

Besides temperature, the proteolytic activity of the fish flesh also plays an important role in gel formation. Proteolytic degradation of proteins by heat-stable alkaline proteases affects the functionality of fish proteins, in particular the gel-forming ability of the protein in different fish.[30] These types of proteases have been found in most fish species, including threadfin bream,[31] carp,[32] Atlantic croaker,[30] white croaker,[33] mullet[34] and Atlantic menhaden.[35] These proteases mostly originate from the gut, and in some cases, eg Alaska pollock, are endogenous to the meat, with optimum activity in the range of 60–75 °C.[36] This type of gel degradation has been reported in washed lizardfish mince.[16,17]

In the case of catla there was no proteolytic degradation of the gel at 50 or 60 °C, but in the case of rohu and mrigal, although suwari setting at 50/60 °C showed an increase compared to lower temperatures, the subsequent cooking resulted in a marginal decrease in gel strength at 50/60 °C. This could be correlated with autolytic activity of major carp muscles.[1] No, or marginally low, autolytic activity was found in all three major Indian carps at 55 °C and pH 5–7. This probably indicates that the modori phenomenon could have been initiated in rohu and mrigal at 60 °C on prolonged setting, but in the case of catla no such phenomenon was seen up to 60 °C. When Pacific whiting muscle was incubated at 60 °C for 30 min before cooking at 90 °C, most of the myosin heavy chain was degraded, affecting its gel strength,[37] and was mediated by cathepsin L.[38,39] The proteolytic activity in fish varies at different stages of life: in chum salmon flesh, high cathepsin and alkaline protease activities were found during the spawning stages,[40,41] while in tilapia the proteolytic activity started at 40 °C and maximum activity was found at 65 °C.[18]

## CONCLUSION

Surimi from rohu, catla and mrigal exhibited good gelling properties. Rohu, catla and mrigal surimi ground with NaCl did not gel at low temperatures, a property generally observed in surimi from marine fish. Good gelling was found at 50 and 60 °C after a setting period of 30 min for rohu and mrigal; in the case of catla, good elastic gels were formed already at 40 °C. Increasing the setting time positively influenced the gel strength only in the case of catla. There was a decrease in gel strength on prolonged setting (60 min) at 60 °C signifying the initiation of the modori phenomenon by the alkaline proteases in rohu and mrigal. In catla, no such decrease was seen up to 60 °C, and this could be related to the absence of heat-stable alkaline proteases in catla meat.

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