

Occurrence of white gelatinous foam on the beaches of Kollam (southwest coast of India) due to the senescent bloom of *Phaeocystis globosa*

Madhu. N. V, Anil. P, Vishal. C. R, Muraleedharan. K. R, Parvathi. A, Gireesh Kumar. T, Arya K.S, Hafza.S

CSIR-National Institute of Oceanography, Regional Centre, Kochi – 682018
Corresponding author: nmadhu@nio.org

Abstract

An unusual white gelatinous foam (~2 feet high) was detected on the beaches of Kollam (Mundakkal), Kerala, southwest coast of India. This foam extended to ~300m alongshore on 10th June 2019, from 7 a. m and sustained till around 10 a.m. CSIR-National of Oceanography, Regional Centre, Kochi conducted a field survey and water sampling in the foam affected coastal region (Kollam) on 11th June 2019 to find out the scientific cause behind the unusual foam formation. Analytical results of the study showed enhanced inorganic nutrients and dissolved forms of organic matter (DOM), carbon (DOC) and nitrogen (DON). The proliferation of a marine Prymnesiophyte, *Phaeocystis globosa* Scherffel ($>320 \times 10^3$ cells L⁻¹) in its diploid flagellate stage was detected in the samples along with a higher abundance of prokaryotes ($>1.2 \times 10^6$ VLPs mL⁻¹) and viruses ($> 4 \times 10^7$ VLPs mL⁻¹). The study revealed that the foam event occurred at Kollam beach area was merely the biogeochemical manifestations of the senescent bloom of *P.globosa*. Furthermore, since the foam formation due to the blooming of *P.globosa* is a rarest coastal event in the tropical marine waters, the first report about it in Indian waters (Kollam beach) is of highly significant when considering its potential impact on the marine ecosystems.

Keywords: Phytoplankton; Algal bloom; Prymnesiophytes; *Phaeocystis*; Kollam

The coastal marine waters are highly prone to the occurrence of various disastrous algal blooms (called as harmful algal blooms-HABs), of diverse phytoplankton functional groups (PFGs). Of which, diatoms and dinoflagellates are the most susceptible bloom causing PFGs in the tropical/subtropical waters¹. However, frequency in the occurrence of HABs of high latitude species has been increasing in the tropical/subtropical coastal waters as a result of potential impacts of anthropogenic climate change². The frequent blooming of such alien species alters the prevailing food-web structures and ecosystem functions of these coastal areas^{3&4}. Recently (10 June 2019), the occurrence of an unusual white gelatinous foam of ~2 feet high (extended ~300 m alongshore) was reported on the beaches of Kollam (Mundakkal), Kerala⁵. This white gelatinous foam appeared early morning at 7 a.m and persisted till 10 a.m. Later on, it gets dissipated from the beach due to the pouring rainfall. The local residents intimated that there were no health issues in connection with the foam event.

A scientific team from CSIR-National Institute of Oceanography (NIO), Regional Centre, Kochi visited the coastal region of Kollam (Mundakkal) on 11th June 2019 and carried out sampling and measurements from two locations (S1- 8° 52' 08.55" N & S2 - 76° 35' 52.59" E) wherein the foam was seen (Fig. 1). At the time of water sampling, the shore experienced high winds (>9 ms⁻¹) and waves (~2 m) and witnessed the formation of white foams from the waves (Figures. 3b & d). Nevertheless, this white foam was not as thick as the gelatinous foam seen the previous day (Figure. 3a). Moreover, faint yellowish foam like patches were also detected in the inshore waters a little off the shore (Figure. 3c). Temperature, salinity, pH, dissolved oxygen (DO), inorganic nutrients⁶, dissolved forms of organic matter (DOM), carbon (DOC) and nitrogen (DON)⁷, phytoplankton pigments⁸ and species abundance and composition⁹, bacterial and viral abundances were determined using oceanographic techniques and protocols¹⁰. For the scanning electron microscope (SEM) based micrographs, the phytoplankton sample was initially rinsed with distilled water and then dehydrated with a graded ethanol series. Subsequently, the dried cell specimens mounted to a stub, and examined using a SEM (Model No. TESCAN VEGA3 SBH) for processing the image. The wind speed (m/s) and wave height (m) data were retrieved from European Centre for Medium-Range Weather Forecasts-enrichment ECMWF (<https://apps.ecmwf.int/datasets/data/interim-full-daily>), and the sea surface temperature (SST) was taken from NOAA Coast Watch-Ocean Watch (<https://cwcgom.aoml.noaa.gov>).

The satellite-derived data (daily mean) showed relatively higher wind speed (9.23 m s⁻¹) and waves (>3 m) all along the coast of Kollam on 10 June 2019 together with a marked decrease in SST (<29.5°C) compared to the previous days (Figures 2a-c). The salinity (34.3), pH (<8) and DO (<4.5

ml/L) of the water samples collected on 11 June 2019, showed the typical hydro-chemical feature of the tropical near-shore waters (Table 1). However, the inorganic nutrients such as, ammonium (5.75 & 1.64 μM), nitrite (0.7 & 0.7 μM), nitrate (4.83 & 4.17 μM), phosphate (1.42 & 1.7 μM) and silicate (63.16 & 21.25 μM) were strikingly higher at both sampling locations (S1 and S2). Likewise, enhanced levels of DOM (338.85 & 361.04 μM), DOC (188.25 & 200.58 μM) and DON (59.2 & 66.91 μM) were also detected in the water samples.

The prokaryotic abundance was relatively low (S1- 1.35×10^6 cells mL^{-1} & S2 - 1.29×10^6 cells mL^{-1}) compared to viral abundance (S1- 4.68×10^7 VLPs mL^{-1} and S2- 4.01×10^7 VLPs mL^{-1}). Chlorophyll *a*, the proxy of phytoplankton biomass, was noticeably higher at S1 (10.21 mg m^{-3}) and S2 (7.23 mg m^{-3}). The phytoplankton marker pigments showed a distinct dominance of fucoxanthin (2.29 & 1.89 mg m^{-3}) over other pigments such as zeaxanthin, chlorophyll *c2*, beta carotene, etc (Table 1). The phytoplankton abundance was substantially higher at S1 (607.16×10^3 cells/L) and S2 (349×10^3 cells/L). The light microscopic (LM, inverted binocular, Leica DMi8) analysis of phytoplankton samples showed an aggregation (40-50 μm long) of randomly distributed oblong (slightly) shaped structures, comprised of ~20-50 solitary cells (Figure 5a). The length and breadth of each of these cells were ~5-6 μm and 2-3 μm , respectively. The SEM micrograph of the solitary cell was much clearer than the LM image for characterizing the morphological features (Figure 5b). The cells were more or less oblong in shape and also a hazy groove like impression was visible in the middle of the cell (Figure 5b). The morphological features of this cellular entity showed the similarities with the original description of the marine prymnesiophyte, *Phaeocystis globosa* Scherffel described by Scherffel¹¹, Kornmann¹² and Rousseau¹³. Actually, in the life cycle of *P. globosa*, there are four distinct cell types. i.e., two types of haploid flagellates (3-6 μm , seen before colony formation), a diploid colonial cell (4-8 μm , embedded in the mucilaginous colony), and a large diploid flagellate (4-9 μm , seen after colony disruption)¹³. Since the *P. globosa* cells detected from the near-shore waters of Kollam was during the decaying phase of the bloom, (i.e, after disruption of the colony), the cell type could be of a diploid flagellate¹³. However, the two flagellae and the haptonema, the characteristic cellular structures of the diploid cell type of *P. globosa*, were not been distinguished properly in the SEM image because of the lack of clarity (Figure 5b). Although, while considering the morphological features of the bloom species as well as the physical characteristics of the foam, it can be categorically assumed that the cellular aggregation encountered in the foam affected near-shore waters of Kollam was the diploid flagellate cell type of *Phaeocystis globosa* Scherffel¹³. The total phytoplankton abundance was comprised of the exclusive aggregations (>80%) of these nanoplanktonic diploid flagellates of *P. globosa* (Table 1).

Although the genus *Phaeocystis* has a worldwide distribution as diverse species, their blooming is mostly restricted in high latitude seas¹³ &¹⁴. Even then, occurrences of *Phaeocystis* blooms have been reported from the tropical waters as well^{4&14}. Usually, *Phaeocystis* spp. lead a polymorphic life, alternating free-living solitary vegetative cells (~3-9 µm) and spherical (mostly) giant gelatinous colonies (up to 5 mm diameter) comprised of >10000 cells¹⁴. The balloon like colonies produce significant amounts of DOM, rich in glucan and mucopolysaccharides in which cells are randomly distributed¹⁴. During the waning phase of the bloom, *Phaeocystis* colonies undergo disruption and release mucus, which ultimately enhances the mucilaginous condition of bloom affected waters and that would eventually cause foam formation^{13&14}. In fact, these white gelatinous foams usually lead to shellfish mortality, production of dimethyl-sulphide, and sometimes becomes a nuisance to shore-based fishing activities^{14&16}. Nutrient stress, especially PO₄ or NO₃ limitation, is considered as one of the major causes of the collapse of *P. globosa* colony¹⁶. As far as the marker pigments are concerned, *Phaeocystis* blooms (particularly *P. pouchetii* and *P. antarctica*) hold two derivatives of fucoxanthin, i.e., 19' hexanoyloxyfucoxanthin and 19' butanoyloxyfucoxanthin¹⁷. However, the natural *P. globosa* bloom does not contain these two marker pigments in higher levels; instead, they contain moderate amounts of chlorophyll *c3* and fucoxanthin¹⁷. The detection of the relative dominance of fucoxanthin and chlorophyll *c3* over other marker pigments from S1 and S2 indicates the natural occurrence of *P. globosa* bloom (Table 1).

Like prokaryotes, viruses also have been recognized as one of the significant members of the marine microbial food web¹⁸. They infect not only the prokaryotes in the marine ecosystems but the whole phytoplankton community as well¹⁸. In *Phaeocystis* cells, viral infection normally induces nutrient remineralization, stimulating bacterial activity and subsequently forces the food web towards a more regenerative system via the microbial loop^{3&18}. The viral lysis of *Phaeocystis* thus enhances release of climatically active organic sulfur compounds (dimethyl sulfoniopropionate-DMSP), the precursor of dimethyl sulfide (DMS)¹⁶. The significant increase of viral count (>4 x 10⁷ VLPs mL⁻¹) observed at S1 and S2, as compared to the previous report¹⁹, points out that there could be putative viruses specified to *P. globosa* and that may be one of the reasons for the termination of blooms in the coastal waters of Kollam¹⁸.

Our study revealed that the foam event reported from the Mundakkal beach, Kollam on 10th June 2019⁵ was due to the post-bloom biogeochemical manifestations of *P. globosa*. The senescent bloom of *P. globosa* observed in the near-shore waters of Kollam may have profusely proliferated a few days before the reported foam event⁵. Later on, gelatinous foams might have evolved from this decayed bloom waters by the prevailing wind action, and subsequently, it might have transported to

the beach area. In fact, the reports of *P. globosa* blooms in low latitude seas are very limited and mostly restricted in the low-latitude upwelling regimes⁴. As far as Indian waters are concerned, *P. globosa* bloom has never been reported elsewhere yet except the one which reported in the open waters of the Arabian Sea (AS)²⁰. Although the southwest coast of India is recognized as one of the major upwelling zones in the eastern AS, the proliferation of *P. globosa* in connection with the upwelling process has never been reported yet. The physical signs of upwelling, in general, on the southwest coast of India could be seen since the second half of May²¹. However, its chemical and biological indications are visible only after June²¹. Indeed, the present foam event was occurred during the onset of southwest monsoon (beginning of June) period. The satellite SST derived data showed a gradual surface water cooling (<29.5°C) in this region since May-end (Figs 4a-c). However, this marginal cooling was not enough to substantiate the occurrence of coastal upwelling in the near-shore waters of Kollam during the foam event period since the sampling locations are too close to the beach. Even then, based on these verifications, we assume that a bloom of *P. globosa* might have developed in the coastal waters of Kollam due to the nutrient enrichments enabled by either coastal upwelling or prevailing water column turbulence prior to the pre-monsoonal (May end to the beginning of June 2019) wind stress and associated rainfall. Since the occurrence of *P. globosa* bloom and the concurrent foam formation is the first report from Indian coastal waters yet, when considering the socio-ecological menaces creating by the extensive *P. globosa* bloom, great concern and alert should be taken to mitigate the large-scale spreading of this HAB species in Indian coastal waters.

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Table captions: -

Table 1- Major chemical and biological parameters from the near-shore waters of Kollam (Mundakkal) on 11th June 2019 (*Bloom species)

Parameters	Sampling locations	
	S1	S2
<i>Chemical</i>		
Salinity	34.3	34.3
pH	7.38	7.91
Dissolved Oxygen (ml/L)	4.43	4.2
Ammonia (μM)	5.75	1.64
Nitrite (μM)	0.07	0.07
Nitrate (μM)	4.83	4.17
Phosphate (μM)	1.42	1.7
Silicate (μM)	63.16	21.25
Dissolved organic matter (DOM) (μM)	338.85	361.04
Dissolved organic carbon (DOC) (μM)	188.25	200.58
Dissolved organic nitrogen (DON) (μM)	59.26	66.91
<i>Biological</i>		
Chlorophyll <i>a</i> (mg m^{-3})	10.21	7.23
Chlorophyll <i>c3</i> (mg m^{-3})	0.67	0.61
Chlorophyll <i>c2</i> (mg m^{-3})	0.37	0.22
B-carotene (mg m^{-3})	0.45	0.23
Fucoxanthin (mg m^{-3})	2.29	1.89
Diadinoxanthin (mg m^{-3})	0.19	0.15
19'butanoyloxyfucoxanthin (mg m^{-3})	0.09	0.05
19'hexanoyloxyfucoxanthin (mg m^{-3})	0.03	0.02
Zeaxanthin (mg m^{-3})	0.94	0.34
Phytoplankton abundance ($\text{No.} \times 10^3 \text{ Cells L}^{-1}$)	607.16	349
<i>Rhizosolenia</i> sp.	-	2.5
<i>Ceratulina pelagica</i>	5	-
<i>Guinardia striata</i>	5	-
<i>Surirella fastuosa</i>	5	-
<i>Navicula</i> sp.	0.01	5
<i>Entomoneis</i> sp.	0.03	2.5
<i>Pleurosigma</i> sp.	0.16	5
<i>Nitzschia</i> sp.	5	-
<i>Pseudonitzschia</i> sp	15	5
<i>Cylindrotheca closterium</i>	5	5
<i>Phaeocystis globosa</i> *	527	324
Viral abundance ($\text{No.} \times 10^7 \text{ VLPs mL}^{-1}$)	4.68	4.01
Prokaryotes ($\text{No.} \times 10^6 \text{ VLPs mL}^{-1}$)	1.35	1.29

Table 1

Figure captions: -

Figure 1-Study area (foam affected region is marked in white bubbles) and sampling locations (Red circles - S1 & S2).

Figure 2-Mean (daily) wind speed (ms^{-1}), wave height (m) (<https://apps.ecmwf.int/datasets/data/interim-full-daily>) and SST ($^{\circ}\text{C}$) (<https://apps.ecmwf.int/datasets/data/interim-full-daily>) in the coastal waters of Kollam during June 2019.

Figure 3 - a) White gelatinous foam layers occurred on the beaches of Kollam (Mundakkal) on 10th June 2019; b-d) Different appearances of foam occurred on 11th June 2019.

Figure 4 - Distribution of mean (daily) sea surface temperature (SST, $^{\circ}\text{C}$) in the eastern Arabian Sea during the onset of southwest monsoon (May/June 2019) - (<https://cwcgom.aoml.noaa.gov>).

Figure 5 - a) LM micrograph of aggregations of *P. globosa*-diploid flagellate cell type; b) SEM micrograph of diploid flagellate type.

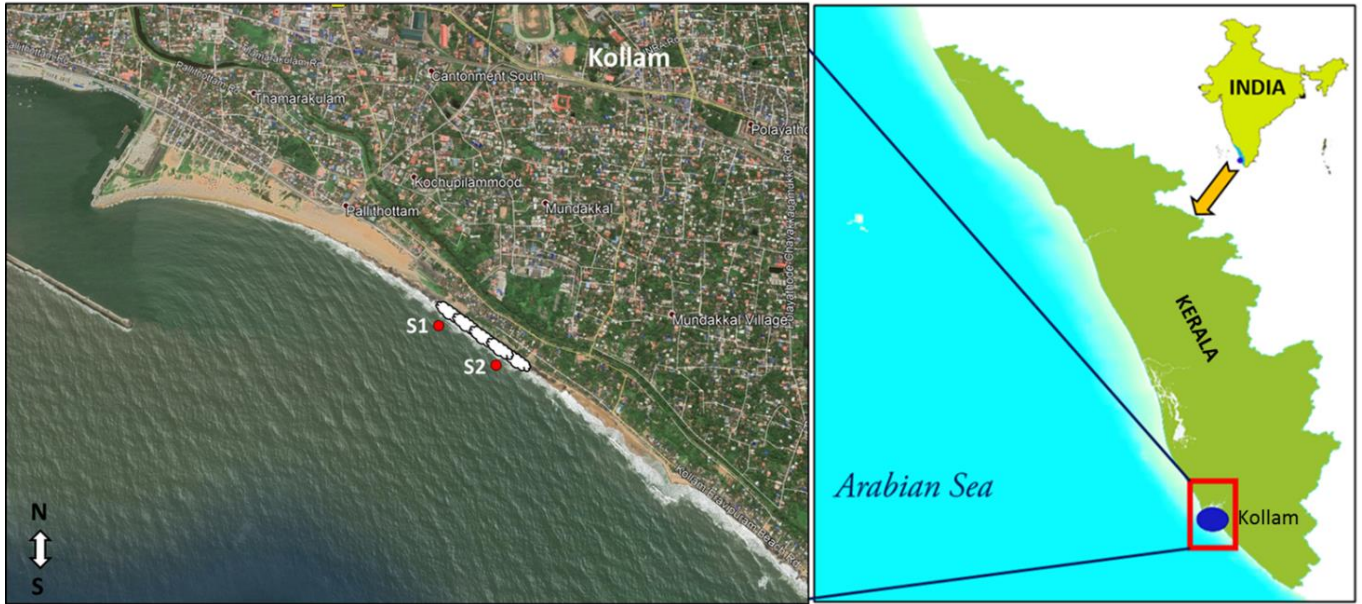


Figure 1

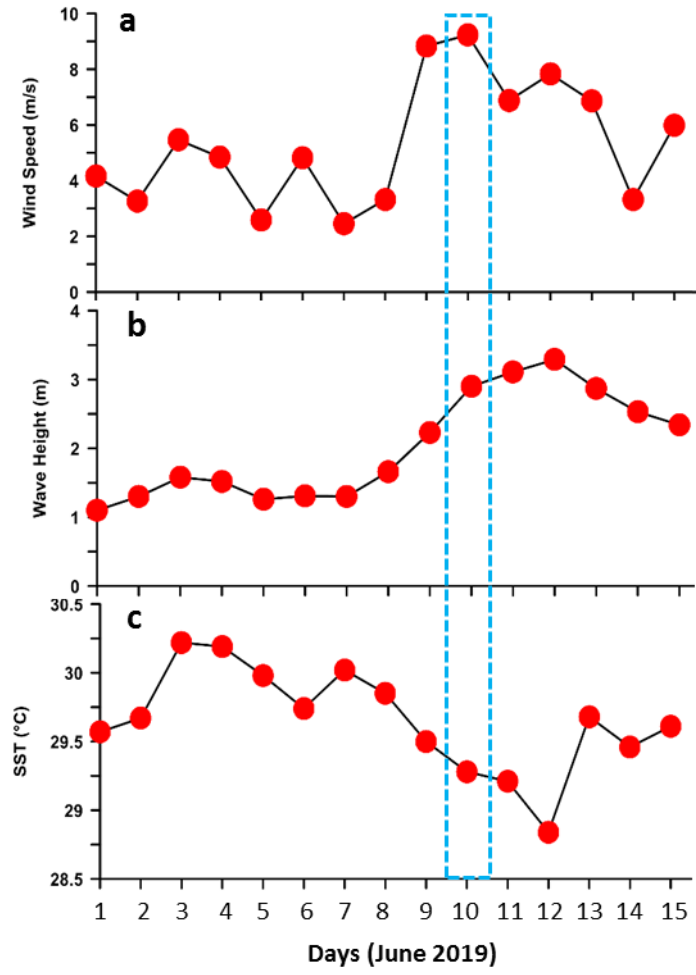


Figure 2



Figure 3

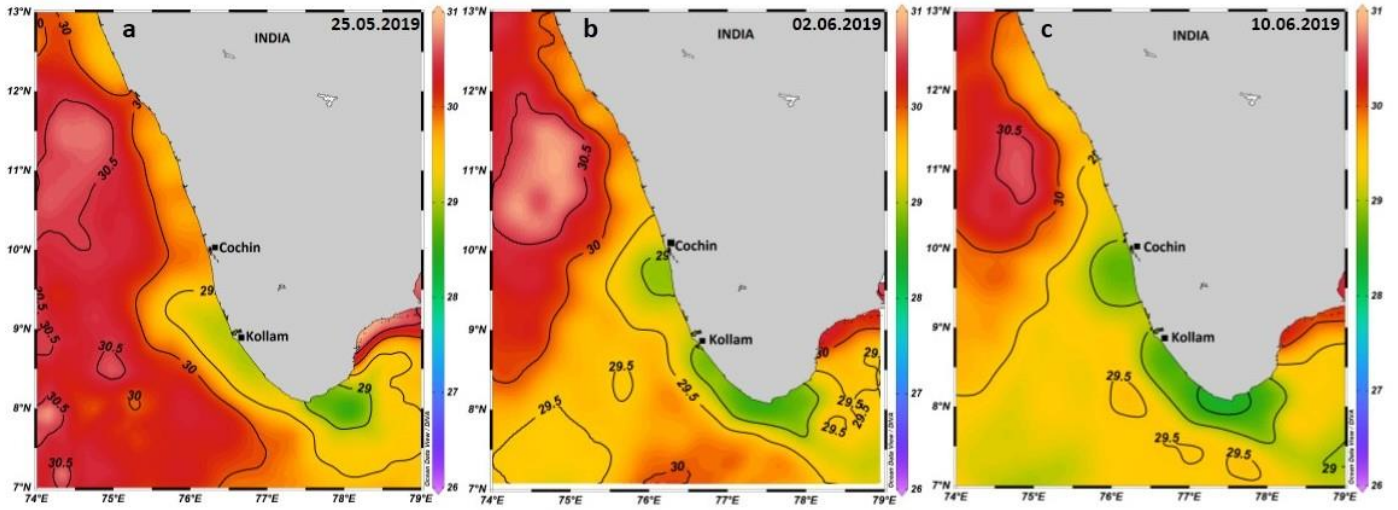


Figure 4

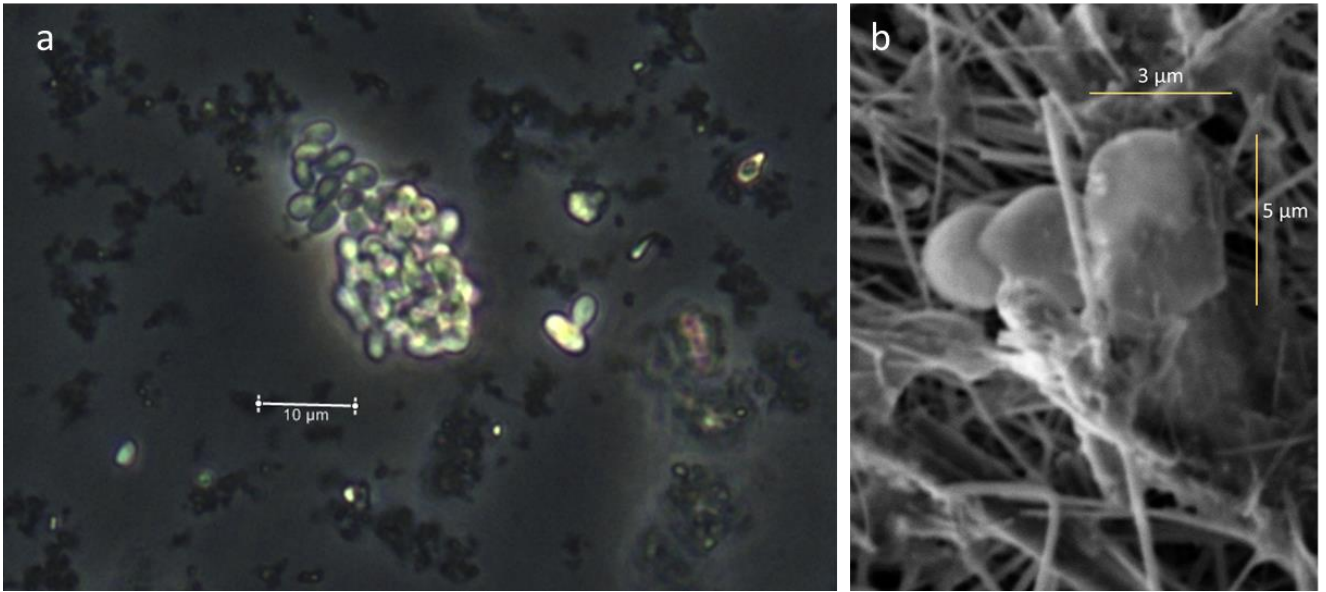


Figure 5