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海州湾不同养殖区紫贻贝的营养特征及其影响因素*

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摘要 为探究海州湾不同养殖区紫贻贝(*Mytilus galloprovincialis*)收获期营养成分变化及其影响因素，于 2021 年 1—3 月测定了海州湾不同养殖区(H1：离岸 1 n mile，H2：离岸 3 n mile，H3：离岸 7 n mile、H4：离岸 13 n mile，H5：离岸 21 n mile)水环境理化因子、紫贻贝的条件指数及蛋白质、脂肪、糖原、氨基酸等营养成分，分析了水体理化因子与条件指数和营养成分的关系。结果显示，随着离岸距离的增加，水温和叶绿素 *a* (Chl-*a*)浓度等关键理化因子均有升高趋势，1—3 月 H1 站位紫贻贝的条件指数逐渐增加，H2~H5 站位的条件指数均在 2 月达到峰值；各站位的紫贻贝总糖含量呈正态分布，于 2 月达到峰值，其中，H4 和 H5 站位总糖含量在 3 月显著下降($P<0.05$)，比 2 月分别降低了 62.7%和 61.6%；H5 站位紫贻贝的氨基酸含量在 1 月显著高于其他站位($P<0.05$)，而后，在 3 月显著降为各站位中最低($P<0.05$)；1—3 月各站位紫贻贝外套膜的糖原含量呈先上升后下降的趋势，而 3 月 H5 站位紫贻贝糖原含量显著高于其他站位。本研究表明，紫贻贝营养物质储备的差异主要与水温和饵料密度有关，离岸养殖更有助于紫贻贝积累营养物质及生长，离岸养殖区紫贻贝性腺成熟早，营养物质积累快，H5 站位紫贻贝比近岸站位可提早 1 个月上市。本研究将为拓展紫贻贝养殖空间、优化养殖布局提供数据参考。

关键词 海州湾；紫贻贝；生长；营养物质

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贻贝又名壳菜，在我国北方俗称海虹，南方称淡菜(毛玉英等, 1993)，是一种营足丝附着生活的双壳类软体动物，有“东方夫人”和“海上鸡蛋”的美誉。2020 年，我国贻贝养殖面积为 4.4 万 hm^2，养殖产量

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超过 88 万 t，是仅次于牡蛎、蛤、扇贝的第四大养殖贝类(农业农村部渔业渔政管理局等, 2021)。紫贻贝(*Mytilus galloprovincialis*)是高蛋白、低脂肪(励炯, 2007)且具有较高的药用和食疗价值的养殖贝类，主要以硅藻和小型浮游生物等为食(孟庆良, 2005)，适应力强、养殖技术简单成熟、产量高，是我国最重要的贻贝养殖品种之一。

海州湾位于山东省与江苏省交界沿岸，属开放型海湾，是我国典型的紫贻贝养殖区，年产量超过 15 万 t，年产值可达 3 亿元。而随着养殖规模扩大，近岸养殖密度增加，同时，由于陆源污染物的输入，导致病害增加、养殖效益降低，为了追求更高的效益，海水养殖逐渐向离岸区发展。张福绥等(1999)提出了将养殖区域扩展到外海海域的“外延稀养”策略，离岸养殖成为发展趋势(刘福利等, 2019)。近年来，得益于养殖技术的进步，海州湾离岸海域已出现紫贻贝养殖，养殖区水环境的不同可能会导致贝类个体生化成分的差异(丁丹勇等, 2018)，但有关近岸和离岸养殖区紫贻贝的生长和营养物质差异尚未见报道。海州湾紫贻贝的春季繁殖期较长，关于双壳贝类繁殖期内生化成分的变化已有相关研究。Li 等(2006)研究了褶牡蛎(*Crassostrea plicatula*)的繁殖周期和生化组成及其与环境因子的关系。程亮等(2013)分析了厚壳贻贝(*Mytilus scoruscus*)不同性腺发育时期内的生化成分变化。而关于紫贻贝在繁殖期的营养物质变化及其与环境因子的关系鲜有报道。本研究分析了近岸和离岸养殖区春季繁殖期紫贻贝营养成分的时空变化特征及其影响因素，并探究了紫贻贝离岸养殖的优势，为拓展紫贻贝养殖空间、提升产品品质，确定最佳的收获时间和优化养殖空间布局提供数据参考。

1　材料与方法

1.1　样品采集

2021 年 1—3 月(每个月采集 1 次)在海州湾不同离岸距离养殖区采集紫贻贝样品和水样。根据养殖区离岸距离设置 5 个站位(图 1)，分别为 H1 (离岸 1 n mile)、H2 (离岸 3 n mile)、H3 (离岸 7 n mile)、H4 (离岸 13 n mile)和 H5 (离岸 21 n mile)；H3、H4 和 H5 站位距岸较远且水深在 10 m 以上，属于离岸养殖区(李大海等, 2019; 刘福利等, 2019)。每个站位采集紫贻贝样品 300 个，并用采水器取 2 500 mL 水样(2 m 深)，同时设置 3 个平行组(取自不同的筏架，每个筏架采集 100 个样品)。使用 YSI (ProODO)现场测定水温、盐度和溶解氧。分别采用分光光度计法和重量法测定叶绿素 *a* (Chl-*a*)浓度、悬浮颗粒物(SPM)和颗粒有机物(POM)含量，测定方法详见《海洋调查规范》(GB12763-2007)。

1.2　样品处理与营养成分测定

样品放入加冰泡沫箱运回实验室，每组随机取 30 个样品用于生物学参数测定。用吸水纸吸去样品壳表面的水分，使用精密分析天平(精确到 0.000 1 g)测量带壳湿重(g)后解剖取出软组织，测量软组织湿重(g)，用电热鼓风干燥箱(DHG-9240A)在 70℃烘干至恒重，称量软组织干重(g)和壳干重(g)，计算条件指数和含水量(Camacho *et al*, 1995)，

$$条件指数(\%)=(软组织干重/壳干重)\times 100\% \quad (1)$$

$$含水量(\%)=(软组织湿重-软组织干重)/软组织湿重\times 100\% \quad (2)$$

取紫贻贝样品的外套膜、斧足和性腺，冷冻干燥 48 h 后采用微量蒽酮法测定糖原含量(陈夕等, 2021; Ojea *et al*, 2004; Mcfarland *et al*, 2016)；烘干后的软组织研磨后用于其他成分测定，蛋白质采用凯氏定氮法(GB 5009.5-2016)进行测定；脂肪采用酸水解法(GB/T5009.6-2003)测定；总糖(以葡萄糖计)参照酸水解-莱茵–埃农氏法(GB 5009.8-2016)测定、氨基酸按酸水解法(GB/T5009.124-2016)测定。

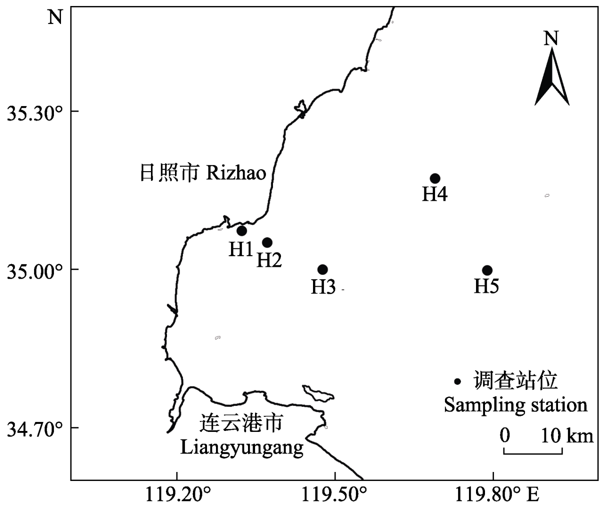

图 1　采样站位设置
Fig.1　Setting of sampling stations

1.3　数据处理

研究数据采用 Excel 2019 和 R 4.0.5 软件进行统计分析，比较各站位环境指标、紫贻贝的条件指数、含水量、营养成分、氨基酸组成和糖原含量的差异，以 $P<0.05$ 作为差异显著水平进行单因素方差分析(one-way ANOVA)。

2 结果

2.1 养殖区理化因子特征

养殖区各站位的环境参数见表 1。3 个月各站位的水温、盐度、溶解氧含量、Chl-*a* 浓度、SPM 和 POM 含量存在显著性差异($P<0.05$)，H5 站位的盐度、溶解氧、Chl-*a* 浓度和 POM 含量显著高于其他站位($P<0.05$)，且随着离岸距离增加，水温、Chl-*a* 浓度和溶解氧含量也有增高的趋势。

表 1 2021 年 1—3 月站位水环境参数

Tab.1 Environmental data of each station from January to March in 2021

月份 Month	站位 Station	水温 Temperature/℃	盐度 Salinity	溶解氧 DO/(mg/L)	叶绿素 *a* Chl-*a*/(μg/L)	悬浮颗粒物 SPM/(mg/L)	颗粒有机物 POM/(mg/L)
1 月 January	H1	4.2±0.10^{d}	28.9±0.10^{b}	9.14±0.15^{e}	1.32±0.10^{e}	32.00±0.05^{a}	6.00±0.10^{b}
	H2	4.3±0.10^{d}	28.5±0.10^{d}	9.84±0.15^{b}	1.94±0.10^{d}	31.00±0.10^{c}	5.88±0.25^{c}
	H3	5.4±0.08^{a}	28.9±0.00^{b}	9.80±0.10^{c}	2.15±0.08^{c}	27.50±0.32^{d}	4.88±0.10^{d}
	H4	5.0±0.12^{b}	28.7±0.10^{c}	9.68±0.10^{b}	2.23±0.10^{b}	22.25±0.27^{e}	4.38±0.10^{e}
	H5	4.8±0.04^{c}	29.2±0.10^{a}	10.13±0.23^{a}	2.56±0.10^{a}	31.50±0.10^{b}	6.80±0.31^{a}
2 月 February	H1	5.1±0.12^{c}	28.9±0.10^{b}	9.08±0.10^{e}	1.45±0.10^{e}	31.50±0.03^{b}	5.84±0.10^{b}
	H2	5.0±0.15^{c}	28.7±0.00^{c}	9.35±0.10^{b}	1.85±0.15^{d}	28.45±0.06^{c}	5.34±0.10^{c}
	H3	5.6±0.13^{a}	28.9±0.10^{b}	9.24±0.08^{c}	2.08±0.10^{c}	28.25±0.10^{d}	5.02±0.34^{d}
	H4	5.5±0.14^{a}	28.8±0.00^{b}	9.16±0.10^{d}	2.14±0.05^{b}	20.35±0.25^{e}	4.16±0.10^{e}
	H5	5.3±0.05^{b}	29.4±0.10^{a}	9.87±0.28^{a}	2.24±0.08^{a}	32.00±0.10^{a}	6.75±0.24^{a}
3 月 March	H1	6.8±0.12^{d}	28.8±0.00^{c}	9.16±0.12^{e}	3.26±0.10^{c}	29.25±0.10^{c}	5.76±0.10^{b}
	H2	6.9±0.09^{d}	28.7±0.10^{c}	9.73±0.05^{c}	3.16±0.10^{e}	29.50±0.06^{b}	5.46±0.10^{c}
	H3	7.1±0.07^{c}	29.1±0.10^{b}	9.76±0.06^{b}	3.23±0.10^{d}	28.50±0.10^{d}	5.10±0.20^{d}
	H4	7.5±0.09^{a}	28.7±0.10^{c}	9.72±0.17^{d}	3.48±0.10^{b}	23.00±0.10^{e}	4.45±0.10^{e}
	H5	7.3±0.02^{b}	29.6±0.20^{a}	10.75±0.20^{a}	3.67±0.10^{a}	33.50±0.10^{a}	7.00±0.27^{a}

注：不同小写字母表示同一月份不同站位间差异显著($P<0.05$)，下同。

Note: Different lowercase letter superscripts indicate significant difference among stations within the same month ($P<0.05$), the same as blow.

2.2 条件指数(CI)与含水量的变化

H2~H5 站位紫贻贝的条件指数在 1—3 月呈先上升后下降的趋势，且均于 2 月达到最大值，H4 站位紫贻贝的条件指数显著高于其他站位($P<0.05$)；H1 站位紫贻贝的条件指数在 1—3 月呈逐渐上升趋势，在 3 月达到最大值(图 2)。H2~H5 站位紫贻贝的含水量在 1—3 月呈先下降后上升的趋势，除 H1 站位外，其他站位紫贻贝含水量的变化规律与条件指数相反(图 3)。

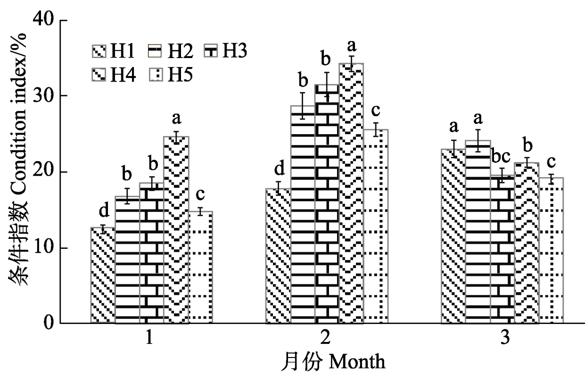

图 2 1—3 月不同站位紫贻贝条件指数的变化

Fig.2 Changes of CI of *M. galloprovincialis* at different stations from January to March

不同小写字母表示同一月份不同站位间差异显著($P<0.05$)，下同。

Different lowercase letters indicate significant difference among stations within the same month ($P<0.05$), the same as blow.

2.3 主要营养成分

海州湾紫贻贝主要营养成分与月份和站位相关联。H1~H3 站位的紫贻贝的蛋白质含量在 1—3 月呈逐渐上升的趋势，而 H4 站位紫贻贝的蛋白质含量在 2 月稍有下降，H5 站位紫贻贝的蛋白质含量在 1—3 月呈逐渐下降的趋势(图 4A)。H1、H3、H4 站位的紫

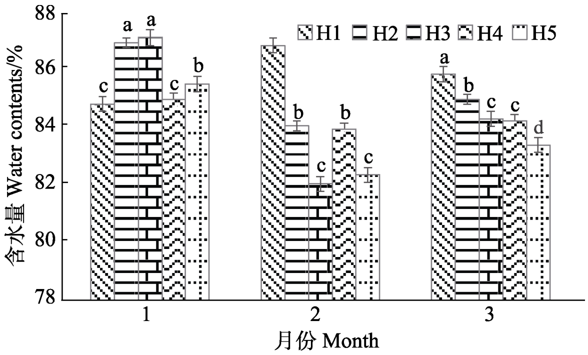

图 3　1—3 月不同站位紫贻贝含水量的变化

Fig.3　Changes of water contents in soft tissue of *M. galloprovincialis* at different stations from January to March

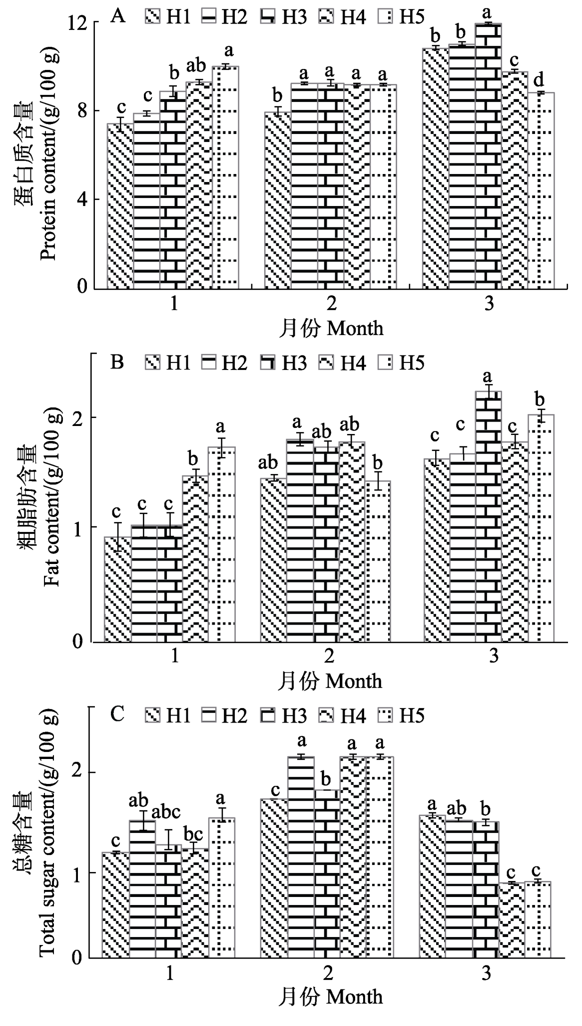

图 4　1—3 月不同站位紫贻贝营养物质含量变化

Fig.4　Changes of nutrient contents in *M. galloprovincialis* at different stations from January to March

贻贝的脂肪含量在 1—3 月逐渐上升，而 H2 站位的紫贻贝脂肪含量在 2 月达到最大值，H5 站位在 2 月出现最小值(图 4B)。所有站位紫贻贝的总糖含量在 1—3 月均呈先上升后下降的趋势，且 H4 和 H5 站位紫贻贝的总糖含量在 2—3 月显著下降，并在 3 月显著低于其他站位(P<0.05) (图 4C)。

2.4　氨基酸组成

如表 2 所示，在 1 月和 2 月，H5 站位紫贻贝的 16 种氨基酸总量和呈味氨基酸总量均显著高于其他站位(P<0.05)；在 3 月，H1 站位紫贻贝的 16 种氨基酸总量最高，H3 站位紫贻贝的呈味氨基酸总量出现最大值。1—3 月 H5 站位紫贻贝的 2 个指标均呈下降趋势。

表 2　1—3 月各站位紫贻贝的氨基酸组成

Tab.2　Amino acid compositions of *M. galloprovincialis* at different stations from January to March

月份 Month	站位 Station	16 种氨基酸总量 Total content of 16 kinds of amino acid/(g/100 g)	呈味氨基酸总量 Total content of flavor amino acids/(g/100 g)
1 月	H1	$5.650\ 0^{d}$	$2.792\ 5^{c}$
January	H2	$5.691\ 2^{d}$	$2.790\ 0^{c}$
	H3	$6.755\ 0^{b}$	$3.350\ 0^{b}$
	H4	$5.945\ 0^{c}$	$3.265\ 0^{b}$
	H5	$8.870\ 0^{a}$	$4.385\ 0^{a}$
2 月	H1	$6.372\ 5^{d}$	$3.085\ 0^{d}$
February	H2	$7.514\ 5^{b}$	$3.617\ 0^{b}$
	H3	$7.462\ 5^{b}$	$3.560\ 0^{b}$
	H4	$7.262\ 5^{c}$	$3.495\ 0^{c}$
	H5	$7.640\ 0^{a}$	$3.703\ 0^{a}$
3 月	H1	$7.865\ 0^{a}$	$3.825\ 0^{a}$
March	H2	$7.547\ 5^{c}$	$3.660\ 0^{b}$
	H3	$7.717\ 5^{b}$	$3.785\ 0^{a}$
	H4	$7.492\ 5^{c}$	$3.582\ 5^{b}$
	H5	$6.480\ 0^{c}$	$3.142\ 5^{d}$

2.5　糖原含量

1—3 月紫贻贝外套膜、斧足和性腺的糖原含量的变化情况见图 5。结果显示，所有站位紫贻贝外套膜中的糖原含量在 2 月达到峰值，而 3 月 H5 站位紫贻贝外套膜的糖原含量显著高于其他站位(P< 0.05)。1—3 月，H1、H4 站位紫贻贝斧足和性腺的糖原含量呈先上升后下降趋势，而 H2、H5 站位紫贻贝斧足和性腺的糖原含量持续上升，H3 站位的紫贻贝斧足的糖原含量在 1—2 月上升，并在 2—3 月保持稳定，而性腺的糖原含量在 1—3 月呈先上升后下降的趋势。

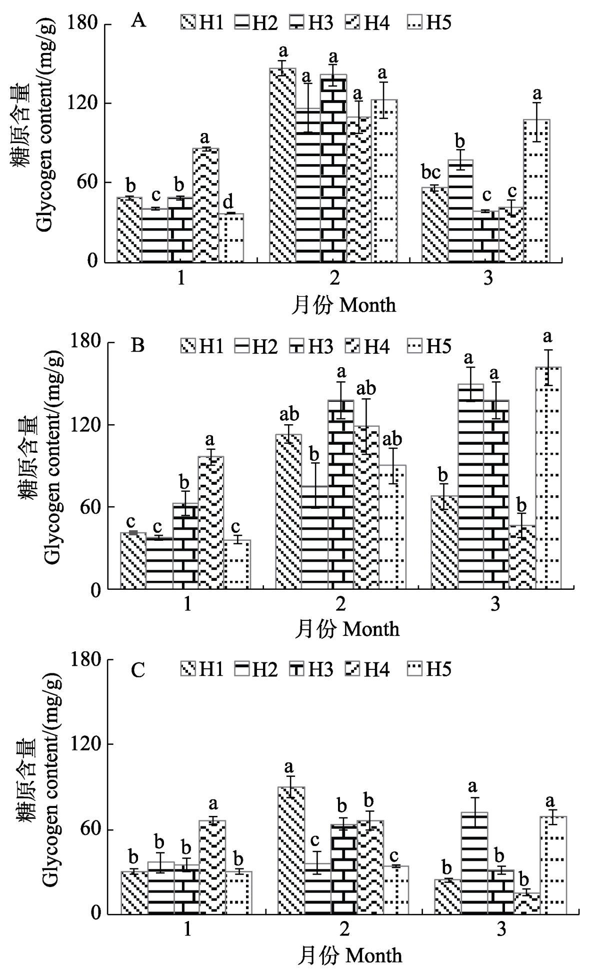

图 5 1—3 月份紫贻贝不同部位糖原含量变化
Fig.5 Changes of glycogen content in different parts of *M. galloprovincialis* from January to March

A：外套膜；B：斧足；C 性腺
A: Mantle; B: Foot; C: Gonad

3 讨论

3.1 紫贻贝营养成分时空差异的影响因素

研究表明，水温、食物密度和洋流特征等可以通过影响贝类的食物可获得性和生理代谢速率来影响贝类的生长、发育和繁殖(Dridi *et al*, 2007; Ojea *et al*, 2004; Ruiz *et al*, 1992)，在贝类的生活史周期内，条件指数通常在性成熟过程中逐渐升高，且随着配子排放而逐渐下降(Kim *et al*, 2005)。在本研究中，H1 站位紫贻贝的条件指数在 1—3 月一直呈现逐步上升的趋势，可判断其在 2 月尚处于生长期，在 3 月或者更晚的时间进入成熟期；而其他站位紫贻贝的条件指数在 2 月到达成熟期后达到峰值，此后，在 3 月随着部分紫贻贝进入排放期而逐渐减小(张福绥等, 1980; 程亮等, 2013)，这可能是由于近岸水域的水温和 Chl-*a* 浓度较低，导致性腺发育所需积温和能量储备不足。贝类软体部的含水量与繁殖周期的肥满度变化密切相关。厚壳贻贝在生长期到成熟期的过程中，随着营养物质的快速积累，组织间隙逐渐被实质性营养物质所填充，软体部的含水量降至最低；进入排放期后因配子的大量排放，组织中的含水量又显著回升(程亮等, 2013)，这与本研究的分析结果一致。从条件指数和含水量的变化来看，除近岸 H1 站位之外的其他站位的紫贻贝在 3 月都已经进入了配子排放期。

许多贝类的脂肪含量的季节性变化与糖原含量的变化趋势相反，表明糖原可能转化成脂肪，为卵黄的形成提供物质和能量(Robert *et al*, 1993)。本研究中，在 1—3 月，各站位紫贻贝呈脂肪含量逐渐增加的趋势，而外套膜和性腺的糖原含量呈下降的趋势，这与其他学者的研究结果一致(程亮等, 2013; 张永普等, 2004)。紫贻贝体内生化成分的变化与配子的合成和释放密切相关(Li *et al*, 2006)，其在产卵季节会消耗体内储存的糖原(Gabbott *et al*, 1973)。糖原是动物配子发生的主要能量储备，生殖周期中，糖原含量的变化反映了为配子发生提供所需能量的策略，即保守策略和机会主义(Shi *et al*, 2019)。紫贻贝在生殖过程中很明显利用了体内储存的糖原提供能量。贝类的性腺发育与温度和浮游植物量密切相关(林志华等, 2004)，本研究中的 H5 站位的紫贻贝发育较快，可能是因为离岸养殖区的平均水温高于近岸养殖区，使得离岸养殖区的紫贻贝在繁殖期内积累的有效积温更高，且 Chl-*a* 浓度和 POM 含量要高于近岸站位，紫贻贝的代谢更快，有助于营养物质的积累，而营养物质的积累决定了生殖腺的发育(Gabbott *et al*, 1973)。

3.2 紫贻贝离岸养殖发展潜力

相比于近岸区域，本研究中离岸养殖区的紫贻贝具备更快的蛋白质和脂肪积累能力，此外，紫贻贝会将糖转化成能量形式更高的脂肪和蛋白质贮存起来，以满足精卵细胞的发育需求(Napolitano *et al*, 1992)。研究表明，厚壳贻贝个体的总糖含量从增殖期开始逐渐下降，并在成熟期达到最低值(程亮等, 2013)。本研究中，各站位紫贻贝的总糖含量在 2—3 月明显下降，且在 H4 和 H5 站位下降最明显，由此初步判断，各站位紫贻贝在 3 月均已进入成熟期，H4 和 H5 站位紫贻贝更快完成能量储存。

动物蛋白的鲜美程度主要取决于蛋白质中的呈味氨基酸的总量(施永海等, 2020)。本研究中，离岸站位 H5 的紫贻贝个体的呈味氨基酸总量在 1 月和 2 月高于其他站位，离岸站位 H3 的紫贻贝在 3 月高于其

他站位，且该站位的紫贻贝的蛋白质、脂肪和总糖含量较高，所以，综合 2 个站位紫贻贝呈味氨基酸总量和其他营养成分来看，H3 站位的紫贻贝适宜在 3 月收获，H5 站位的紫贻贝适宜在 2 月收获，离岸养殖的紫贻贝在2月即可上市,比近岸区域早接近1个月。离岸养殖紫贻贝提早上市可以延长贻贝上市供应时间，降低集中上市导致的竞争压力，另外，离岸养殖紫贻贝的养殖周期短、养殖空间大、口感好，具有较好的市场潜力。近年来，得益于互联网技术的发展，网络销售已经成为各行业的重要销售渠道，这种方式可以避开第三方直接销售给顾客，商品单价更高，市场巨大；结合离岸养殖紫贻贝的优势，养殖户可以利用网络销售实现再度增收。

近海区域的环境问题是阻碍紫贻贝产业良性发展和增产提效的主要客观因素(程海等, 2019; 唐启升等, 2013)，而与近岸海域相比，离岸海域空间大、水体交换频繁、营养盐充足、饵料密度高、陆源污染物风险低(李大海等, 2019)，具有较好的养殖优势。近年来，新英格兰地区为提高贻贝水产养殖产量开始将养殖区转移到离岸海域(Fairbanks *et al*, 2016)，虽然离岸养殖需要的成本和技术更高，但离岸养殖的综合效益还是很可观的(刘福利等, 2019)，发展离岸养殖有利于优化海洋开发的空间结构，提高食物生产的整体效率，缓解食物生产的资源环境压力，培育形成新的海洋技术优势和产业优势(李大海等, 2019)。

本研究通过对不同离岸距离养殖区紫贻贝在 1—3 月的条件指数、营养成分、氨基酸和水环境理化因子的变化发现，离岸养殖区紫贻贝的营养成分和氨基酸在 2 月含量丰富，而近岸养殖区紫贻贝营养成分积累缓慢，这种营养物质储备的差异主要与水温和饵料密度有关，离岸养殖区更有利于紫贻贝营养物质积累及生长。

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Factors Influencing the Nutritional Characteristics of *Mytilus galloprovincialis* from Different Culture Areas in the Haizhou Bay

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Abstract *Mytilus galloprovincialis* has high-protein and low-fat contents, as well as medicinal and therapeutical values. It is one of China's most important mussel breeding species, with strong adaptability, mature and straightforward breeding technologies, and high yield. It mostly feeds on small plankton, with main nutrients varying seasonally with different growth stages, and the individual biochemical components of the same species also differ geographically. The change of bait is also an important factor in changing the volatile substances of this shellfish. The mussels' nutritional flavor characteristics have been a concern of national scholars. However, the nutritional and flavor characteristics of *M. galloprovincialis* in different cultural areas have not been reported yet. Haizhou Bay is the main *M. galloprovincialis* aquaculture area in China, with an annual output of more than 150 000 tons and a value of 300 million yuan. Mussels cultivated in five sites (H1 to H5) in this region were collected once every month, from January to March. H1 is one nautical mile off the coastline; H2 is 3, H3 is 7, H4 is 13, and H5 is 21 nautical miles off the coastline. The physical and chemical factors of these water environments and the protein, fat, total sugar, and glycogen contents within the soft tissues of the sampled mussels were measured. The results showed that the *M. galloprovincialis* nutrient content varied among sampling time and sites and was directly related to the gonad development. The H1 condition index increased continuously from January to March, and the mussels' highest condition index in other areas was found in February. The highest total sugar content of mussels collected in all regions was observed in February, while for the H4 and H5 areas, it decreased significantly in March and was 62.7% and 61.6% lower than that in February, respectively. These changes were mainly caused by *M. galloprovincialis* entering its breeding season in March. The total content of 16 amino acids and the content of flavorful amino acid at H5 were significantly higher than those in other regions in January (P<0.05). However, these amino acid levels decreased significantly and became the lowest in March for the mussels sampled in the H5 region. From January to March, the glycogen content in the mussel mantle increased firstly and then decreased, while its highest level was found in mussels collected in H5 in March. Most of the cultivated *M. galloprovincialis* are sold in winter. Here we observed that the gonad development and nutrients and flavor amino acids levels of the offshore mussels were different from those of the nearshore mussels, and the offshore mussel completed the material and energy storage earlier and entered the breeding period sooner, suggesting that the best marketing time is different for the studied areas. Differences in the mussels′ nutrient reserve were mainly related to temperature and feed density. The water temperature and the Chlorophyll-*a* (Chl-*a*) concentration tended to increase with

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the offshore distance rise, leading to the rapid development and early marketing time of *M. galloprovincialis* in the studied offshores. In February, mussels in the H5 area were rich in nutrients and flavor materials; therewith, they could be marketed one month earlier than in other areas. Early listing of the offshore cultured mussel can prolong its market supply time and reduce the competitive pressure caused by centralized listing. In addition, the offshore cultured mussel has a good market potential because of its short breeding cycle, wide breeding space, and good taste. In recent years, thanks to the development of internet technology, online sales have become an important sales channel in all industries. This way avoid the third-party vendor, wherein the producer can sell directly to customers with higher unit prices and a vast market. Combined with the advantages of offshore mussel cultivation, farmers can use online sales to increase their income further. With the increase in the density of offshore aquaculture in the Haizhou Bay, harmful algal blooms threaten the safety of shellfish products. Environmental problems in nearshore areas are the main factors hindering the favorable and productive development of the *M. galloprovincialis* industry. Therefore, the development of offshore aquaculture has great potential. Compared with the nearshore sea, the offshore sea has more extensive space, frequent water exchange, and larger environmental capacity. In order to improve the output of mussel aquaculture, New England began to transfer the aquaculture area from the nearshore to the offshore sea. Although the cost and technology needed for the offshore culture are significant, the comprehensive benefits of the offshore culture are still considerable. The offshore aquaculture development is conducive to optimizing the spatial structure of the marine industry, improving the overall efficiency of food production, alleviating its resource and environmental pressures, and cultivating new marine products with technological and industrial advantages. This study may provide supportive data for optimizing the spatial layout planning and harvesting time of *M. galloprovincialis* offshore cultivation.

Key words Haizhou Bay; *Mytilus galloprovincialis*; Growth; Nutrition