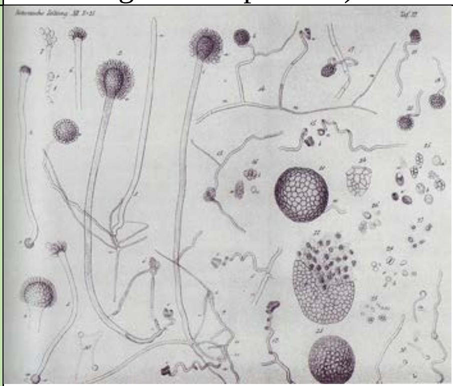
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	離散分子的低溫保護作用 (Chaotropic molecules protect from low temperature)
生物系統 LIVING SYSTEM	臘葉散囊菌 *Eurotium herbariorum*
功能類別 FUNCTIONS	#保護免受溫度危害 #改變材料特性 #Protect from temperature #Modify material characteristics
作用機制標題	臘葉散囊菌可產生水溶性分子當作潤滑劑，進而在低溫下確保生物化合物的正常功能。 (*Eurotium herbariorum* can survive at low temperatures by producing water-soluble molecules that act as lubricants to ensure proper function of biological compounds.)
生物系統/作用機制示意圖	

作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)

低溫會導致分子之間非共價的相互作用增加。也就是說與高溫環境下相比，它們使分子更傾向「黏」在一起。這導致細胞內的大分子及細胞膜的硬化，是低溫下細胞死亡的主要原因。有一種類別廣泛地的溶質（稱為離散物質 chaotroph），在所有溫度下均會產生更無序（即更少的黏性）的相互作用，因此能避免分子在低溫環境下的硬化。相比之下，在中溫到高溫環境下，離散物質會導致無序的交互作用，這將使細胞產生不適當的反應造成細胞壓力。已知的離散劑包括氯化鎂，氯化鈣、甘油、果醣和尿素。而被稱為聚合物質 (kosmotroph) 的各類溶質，其作用機制恰好相反，它們促進分子之間非共價的相互作用，從而導致低溫下分子間的相互作用較差，高溫下則較好。

高溶質耐受性耐旱的 (xerophilic) 的真菌，臘葉散囊菌 (*Eurotium herbariorum*)，在低溫環境下，已被記錄到其細胞內會累積環境中的離散物質如果醣，並合成新的離散物質如甘油。在低溫下，真菌會避免積累聚合物質。觀察到的低溫下增加累積或合成離散物質之行為，或許與較高的生長及生存率相關。此外，有證據指出在高溫環境下累積及合成較多的聚合物質能較有利於生存。綜上所述，這些證據極有可能表明臘葉散囊菌能夠控制其細胞內分子的交互作用，進而有利在低溫下存活。離散物質的累積和合成能幫助細胞在通常會導致分子硬化和細胞死亡的溫度下，仍維持天然的生化功能。

Low temperatures cause an increase in the non-covalent interactions between molecules. In other words, they cause molecular scale objects to "stick" together more favorably than they would at higher temperatures. This leads to the rigidification of cellular macromolecules and membranes which is a major cause of cellular death at low temperatures. A broad category of solutes, called chaotrophs, create more disorderly (i.e., less sticky) interactions at all temperatures, and therefore prevent molecular rigidity at low temperatures. In contrast, at moderate to high temperatures, the disordered interactions that chaotrophs promote lead to improper mechanics that cause cellular stress. Known chaotrophs include magnesium chloride, calcium chloride, glycerol, fructose, and urea. Conversely, a broad category of solutes called kosmotrophs perform in the exact opposite role; they promote non-covalent interactions between molecules which leads to poorer performance at low temperatures and higher performance at high temperatures.

The highly solute tolerant (xerophilic*) fungus *Eurotium herbariorum* has been documented accumulating environmental chaotrophs like fructose in its cells at low temperatures as well as synthesizing new ones like glycerol. The fungus actively shunned accumulation of kosmotrophs at these low temperatures. This accumulation/synthesis of more chaotrophs at low temperatures is likely to be partly responsible for the higher growth and survivability observed. Furthermore, evidence of relatively higher kosmotroph accumulation and synthesis at high temperatures correlated to higher survivability. Taken together, the evidence is highly suggestive that *E. herbariorum* is able to manipulate the molecular interactions within its cells to its benefit at low temperatures. The increased accumulation and synthesis of chaotrophs helps the cells maintain natural biochemical function at temperatures that would normally result in rigidity of molecules and cell death.

文獻引用 (REFERENCES)

已知可使細胞大分子紊亂（離散）的物質能增加微生物生長的機會，真菌在低溫下優先積累離散作用代謝產物，溶質的化學活性決定了在極端溫度和逆境下的微生物存活率…細胞內部和細胞間結構相互作用直接或間接依賴於水分子。一般情況下，低溫會促進非共價相互作用，從而使細胞內的大分子和細胞膜硬化。相反地，離散溶質已知會使大分子系統失序...在許多情況下，離散物質會作為壓力源，並可以讓微生物在次佳的生長溫度下增強細胞活性，增加微生物細胞在寒冷環境下的存活機率...微生物活性不僅減少，而且與較高的溫度相比，在添加果醣...離散物質的培養基上有最佳的生長速率。(Chin et al. 2010: 7835)

這些數據表明了離散溶質明顯促進了低溫環境下的生長，而與真菌種類無關…一系列化學上不同的離散劑（即甲醇、氯化鎂和甘油）…儘管不同溶質表現其離散活性的機制尚不清楚，但離子性、非離子性和疏水性的離散劑對細胞的淨作用可能沒有差別…在低於零度的環境中，與聚合劑培養基相比，添加了離散劑的所有培養基中的生長速率顯著提升…雖然在 30˚C 的環境下，聚合性蔗醣培養基比離散性的果醣培養基中，所觀察到

的生長速率高出 200％以上，但在低溫（+5˚C 和+1.7˚C）下則相反…[在低溫下] 添加蔗醣的培養基上生長的真菌沒有積累蔗醣，也沒有合成諸如海藻醣、甘露醇、阿拉伯醣醇或赤蘚醣醇等聚合相容性溶質…細胞優先合成並積累了離散相容性溶質的甘油...經離散劑處理的分生孢子在高溫和高壓下存活率下降了 30%至 93%（無論真菌種類如何），但事實上在暴露於-20°C 或-80°C 溫度下的分生孢子，在 24 小時後存活率並沒有多少的下降 (≤5%)。對於經聚合劑處理的分生孢子，觀察到相反的趨勢，在曝露於低溫後存活率下降達 60%，但是在曝露於高溫和高壓下後相對存活率則高達 96％，並與溶質無關。(Chin et al. 2010: 7836)

環境相關物質的溶質活性決定了微生物細胞在溫度區間 (temperature window) 的存活和生長機會...此現象的基礎機制與物理化學上多樣的應力參數影響細胞大分子結構相互作用相關。高溫和離散活性會中斷相互作用，例如脫水等因子，而低溫和聚合性溶質則促進了相互作用...在一定條件下，微生物細胞可以通過遺傳方式來控制優先產生或累積離散代謝產物，例如甘油和果醣，促進大分子相互作用，以在代謝活性和細胞分裂達到受限制程度的環境中存活（例如溫度接近或低於 0˚C）。(Chin et al. 2010: 7836-8)

“[S]ubstances known to disorder cellular macromolecules (chaotropes) did expand microbial growth windows, fungi preferentially accumulated chaotropic metabolites at low temperature, and chemical activities of solutes determined microbial survival at extremes of temperature as well as pressure...Structural interactions within and between cellular macromolecules are dependent, either directly or otherwise, on water molecules. Generally low temperatures promote noncovalent interactions and, thereby, rigidify cellular macromolecules and membranes. Conversely, chaotropic solutes are known to disorder macromolecular systems...chaotropic substances which under many circumstances act as stressors can, nevertheless, enhance cellular activity at suboptimal growth temperatures and thereby extend the biotic windows of microbial cells in cold environments...microbial activity was not only diminished, but in contrast to higher temperatures, growth rates were optimal on media supplemented with fructose...which is chaotropic.” (Chin et al. 2010: 7835)

“[T]hese data demonstrated an apparently potent promotion of growth at low temperature by a chaotropic solute, irrespective of fungal species...a range of chemically diverse chaotropes (i.e., methanol, $MgCl_2$, and glycerol)...Although the mechanisms by which diverse solutes exert chaotropic activity are not yet well-understood, the net effects of ionic, nonionic, and hydrophobic chaotropes may be indistinguishable to the cell...growth rates were greatly enhanced on all chaotrope-supplemented media relative to that on the kosmotropic medium at subzero temperatures...Whereas the growth rate was more than 200% higher on the kosmotropic sucrose medium relative to that observed on the chaotropic fructose medium at 30 °C, the converse was true at low temperatures (+5 °C and +1.7 °C)... [at low temperatures] Fungi grown on the sucrose-supplemented medium did not accumulate sucrose nor did they synthesize a kosmotropic-compatible solute such as trehalose, mannitol, arabitol, or erythritol...cells

preferentially synthesized and accumulated a chaotropic-compatible solute, glycerol...Whereas conidia subjected to chaotrope treatments lost between 30% and 93% of their viability at high temperatures and high pressures (regardless of fungal species), there was virtually no loss of viability (≤5%) after a 24-h period of exposure to temperatures of −20 °C or − 80 °C. The converse trend was observed for kosmotrope-treated conidia, which lost up to 60% viability after exposure to low temperatures but survived relatively well (up to 96%) after exposure to high temperatures and pressures, regardless of the solute.” (Chin et al. 2010: 7836) “[T]he solute activities of environmentally relevant substances determined the temperature windows for both survival and growth of microbial cells...mechanistic basis of this phenomenon correlates with the way in which physicochemically diverse stress parameters influence the structural interactions of cellular macromolecules. Whereas high temperatures and chaotropic activity disrupt interactions, factors such as desiccation, kosmotropic solutes, and low temperature promote interactions...microbial cells may be genetically hardwired to preferentially produce and/or accumulate chaotropic metabolites, such as glycerol and fructose, under conditions that promote macromolecular interactions to an extent that limits metabolic activity and cell division (e.g., temperatures close to and below 0 °C).” (Chin et al. 2010: 7836-8)
參考文獻清單與連結 (REFERENCE LIST)
Chin, J. P., J. Megaw, C. L. Magill, K. Nowotarski, J. P. Williams, P. Bhaganna, and J. E. Hallsworth. (2010). Solutes determine the temperature windows for microbial survival and growth. *Proceedings of the National Academy of Sciences* 107: 7835-7840. (https://www.pnas.org/content/107/17/7835.short)
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生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)
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