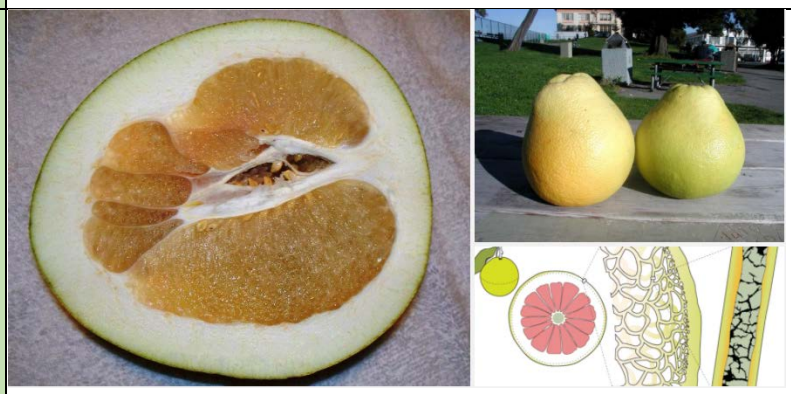
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	多層次組織的果皮賦予抗衝擊力 (Hierarchical organization of peel confers impact resistance)
生物系統 LIVING SYSTEM	柚子 *Citrus maxima* (Pomelo)
功能類別 FUNCTIONS	#應付衝擊 #防止破裂/斷裂 #Manage impact #Prevent fracture/rupture
作用機制標題	柚子果實由於其複合果皮的層次組織而有絕佳的減震特性 (The pomelo fruit has excellent damping properties due to the hierarchical organization of its composite peel)
生物系統/作用機制示意圖	

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

文獻引用 (REFERENCES)

「天然材質常常會展現絕佳的力學特性。有著驚人抗衝擊能力的一個例子就是柚子 (*Citrus maxima*) 的果實，它可以從十公尺的地方掉下而不會有明顯的外部損傷。我們的數據推測這種抗衝擊能力是由於果皮 (pericarp) 的多層次組織構造。」(Fischer 2010: B658)

「柚子是柑橘屬中有最大果實的物種，一顆果實可以重達 6 公斤，結果植株最大高度可達 15 公尺。果實重量及結果枝條的高度這兩個因素組合起來， 造成了懸掛在樹上果實的高位能。當果實掉落時，位能轉換成動能並在即將與地面衝擊時達到最大。如果這巨大的動能使柚子在衝擊地面時裂開，果實將會因為其原產地東南亞的熱帶氣候而在短時間內腐壞。」(Fischer 2010: B659)

「柚子果皮薄切片 (thin section) 的半定量分析 (Semi-quantitative analyses) 揭示了外果皮 (exocarp) 跟中果皮 (mesocarp) 之間的密度逐漸地轉變。因此在結構上，高密度的外果皮並不能與海綿狀的中果皮明確地分隔開。我們的假說是由於缺乏組織組成分的突然改變，因此在結構及力學特性上，果皮組織因為衝擊而剝離 (delamination) 的風險因而降低了。作用在柚子上的衝擊力取決於果實衝擊前的速率及其重量，但亦取決於地

面的組成的一致性 (consistency)。在自然條件下，部分的總能量會消散到相對易彎曲 (pliable) 的地面上，就像典型的柚子自然生長的地區。在測試中，把果實投擲在堅硬的地面上，作用在果實上的力學負載即增加。因此所有的動能都會消散於果實本身。中果皮充滿空氣的細胞間隙 (intercellular space) 作用為可擠壓的泡棉 (foam)。由於這個果皮海綿狀部分的楊氏模數 (Young's modulus) 相對地低，我們推斷其消散大量能量的能力應該是來自果皮的結構組成。」(Fischer 2010: B662)

"Natural materials often exhibit excellent mechanical properties. An example of outstanding impact resistance is the pummelo fruit (*Citrus maxima*) which can drop from heights of 10 m and more without showing significant outer damage. Our data suggest that this impact resistance is due to the hierarchical organization of the fruit peel, called pericarp." (Fischer 2010: B658)

"*Citrus maxima* is the largest fruit among the genus *Citrus* with a fruit weight up to 6 kg and a maximal height of the fruit bearing trees of 15 m. In combination these two factors, fruit weight and the height of the fruit bearing branches, cause a high potential energy of the hanging fruit. After the fruit is shed its potential energy is converted into kinetic energy which reaches its maximum just before impact with the ground. If the high kinetic energy was to cause the pummelos to split open when impacting with the ground, the fruits would perish within a short time due to the tropical climate in Southeast Asia, the region of origin of the genus Citrus." (Fischer 2010: B659)

"Semi-quantitative analyses of thin sections of pummelo peel revealed a gradual transition in density between exocarp and mesocarp. Thus, structurally, the dense exocarp cannot be separated clearly from the spongy mesocarp. We hypothesize that due to this lack of an abrupt change in tissue composition and therefore in structural and mechanical properties the risk of delamination of the tissues during impact is reduced. The impact force acting on the pummelo depends on the velocity of the fruit before impact and its weight, but also on the consistency of the ground. Under natural conditions, part of the total energy is dissipated by the relatively pliable ground, as typically existing in the regions where pummelos grow naturally. In the tests presented mechanical loads acting on the fruits were increased by dropping the fruits onto a hard ground. Thus all kinetic energy must have been dissipated by the fruits themselves. The mesocarp with its air-filled intercellular spaces represents a compressible foam. As the Young's modulus of this spongy part of the peel is rather low, we conclude that its ability to dissipate large amounts of energy must result from the structural composition of the peel." (Fischer 2010: B662)

參考文獻清單與連結 (REFERENCE LIST)

Fischer, S. F., M. Thielen, R. R. Loprang, R. Seidel, C. Fleck, T. Speck, and A. Bührig-Polaczek. (2010). Pummelos as concept generators for biomimetically inspired low weight

structures with excellent damping properties. *Advanced Engineering Materials* 12: B658-B663. (https://doi.org/10.1002/adem.201080065)

延伸閱讀

Zhang, G. (3 October, 2018). Pomelo peel bioinspired foam. *AskNature*. Retrieved from: https://asknature.org/idea/pomelo-peel-bioinspired-foam/

生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)

https://en.wikipedia.org/wiki/citrus_maxima
https://www.onezoom.org/life/@citrus_maxima
https://eol.org/pages/488254

撰寫/翻譯/編修者與日期

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AskNature 原文連結

https://asknature.org/strategy/hierarchical-organization-of-peel-confers-impact-resistance/