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生物科学

光环境生物效应及其模拟实验装备研究进展

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摘 要 光是人、动物和植物赖以生存的基本条件。光环境作为一种物理环境因素,其生物效应具有十分重要的理论和应用价值。光环境对人的生理、心理及行为产生重要影响,对动物昼夜节律、定位系统和生长繁育的影响也已受到诸多关注;同时,光是植物赖以生存的基础,是植物一切生化反应的能量来源。综述了光环境生物效应的研究进展,指出已有的文献仅限于以复色光为研究对象,对特定波长的光效应、光暴露时间及光质效应的研究甚少。进一步阐明目前光环境模拟实验装备的研制所遇到的关键"瓶颈"是缺乏能够在一定波长范围内输出较高功率的单色光光源,且无配备生物学培养装置,不可能在实验室实现对单色光环境的模拟。因此,其发展当务之急是先构建光环境暴露的科学实验平台。同时对光环境生物效应的研究方向及光模拟实验装备的应用前景进行了展望。

关键词 光环境 生物效应 模拟 装备 进展
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光是一种重要的物理环境因素。光环境的生物效应也称光的非视觉效应,是指光通过视网膜神经节感光细胞的作用,参与激素、生理体征、昼夜节律等的调节过程。随着科技的进步,人造光源的使用打破了亿万年来以太阳光的昼夜循环为基础的自然规律。已有许多文献报道光环境的变化给生物体带来极大影响。本文综述了光环境对人、动物、植物的影响,并展望了光环境模拟实验装备的未来发展方向。

1 光环境的生物效应研究进展

1.1 光环境对人类健康的影响

1.1.1 对人生理的影响

光环境的变化是主导人体睡眠以及昼夜节律的主要因素[1]。研究认为436~456 nm的短波长光与复色光类似,能诱导人体生理节律的相位提前,所需光子含量仅为复色光的1/185[2]。同时,460 nm的短波长光能有效抑制人体褪黑激素水平[3,4]。460 nm波长的低强度单色光比555 nm左右的光(视锥细胞特征吸收峰)对人生理节律和相位的影响更大[5]。青少年睡前在光照下暴露1 h和2 h后,血清中褪黑激素含量分别下降了23%和38%;且他们对光的敏感性高于成人[6]。已有研究表明夜晚的灯光会导致生物钟紊乱,褪黑激素分泌受到抑制,导致DNA损伤,增加癌变概率[7,8];女性乳腺瘤的发生与褪黑激素分泌的抑制有关[9],但光照是否会增加患乳腺癌概率尚有争议,一些研究表明夜班工作女性往往会面临罹患乳腺癌概率增加的风险[10,11],但有学者指出不能对乳腺癌与光照的关系过早下定论[12]。此外,光暴露还能引起人核心体温[13]和心率[14]升高等急性生理反应,通过脑电图还可观察到光使人产生警觉反应[13,15]。人们长期暴露在过量的或不协调的光环境中也会引发头晕、失眠、心悸、发烧等症状[16]。

1.1.2 对人心理及行为的影响

人眼对于不同颜色光的敏感性有着数量级的差异,缤纷的色彩光源会对人类大脑中枢神经功能产生影响[16]。如光的色温高低给人造成不同的心理反应[17]。低色温使人嗜睡,高色温能提高人对工作的紧张性和警觉水平,使人注意力集中[18],有助于

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脑力活动效率的提高。已有学者对光的照度和色温两个参数进行了综述[19]。韩国学者的研究发现,儿童在绿光环境中注意力最集中,蓝光环境中记忆力最高[20]。同时,光的闪烁或反射光都会影响儿童的注意力[21]。医学方面的研究显示,光环境有助于降低婴儿的心率、活动水平和呼吸频率[22,23]。医院病房的日照量会影响患者的心理健康和疼痛药物的摄入量[24]。强光可以有效减轻双相情感障碍或季节性情绪障碍患者的抑郁[25—27]。Benedetti 等[25]在研究 415 名单相情感抑郁和 187 名双相情感抑郁患者住院期间的表现时发现,上午直射阳光的暴露,使双相情感障碍患者住院时间平均缩短了 3.67 d,但单相抑郁患者不受光暴露的影响。另据调查,住在缺乏光照的疗养院的居民每晚醒来的次数最高达 37 次[28],睡眠质量极差。但由于早期有报道荧光灯会使自闭症儿童变得更分心[29],闪烁的荧光灯使老年痴呆症患者变烦躁,甚至引发癫痫[30]。因此,德国禁止卫生保健机构使用冷白色荧光灯,他们认为老年人可能需要更多种光线以获得适当的视觉清晰度[28]。

基于光对人体生理和心理影响,医疗上已开发了一系列光疗仪用于治疗疾病。基于胆红素对波长为 460 nm 的光的吸收[31],临床上用波长为 425 ~ 475 nm 的蓝光或 460 ~ 490 nm 的蓝绿光治疗新生儿黄疸[32],光的强度[33]和面积[34,35]等与治疗效果有直接关系。LED 光疗仪[36]在临床上已得到广泛使用。研究还发现,合适的光照条件可有效缓解痴呆病人的病情[37],可用于治疗季节性情绪低落、睡眠紊乱[38]和产后抑郁[39]。然而,也有研究表明光疗会诱发临床不规则痣的产生,加大黑色素瘤的风险[40]。

光对人心理及行为的影响研究已取得一定进展,但遗憾的是,这些研究大多以复色光为研究对象,究竟是哪个波长或波段的光在人心理和行为上起主导作用,尚未见文献涉及。

1.2 光环境对动物的影响

光是动物所处环境中的一个重要组成部分,对多种动物的生存起关键作用[41]。

1.2.1 光环境对动物的昼夜节律的影响

由于人造光的干扰,蝙蝠在黎明和黄昏原本存在的两个活动高峰消失了[42]。光暴露通过掩蔽动物体内源性时钟而使一些温带鸟类黎明啼叫时间提前[43],并对其繁殖产生影响[44]。夜间低强度的光环境可能会扰乱鱼类、鸟类和哺乳动物褪黑激素的分泌,导致一系列的生理反应[45]。目前对干扰昼夜节律所需的光场条件还不明确,但已有研究表明城市天空辉光或短暂的汽车灯光都可能打破动物正常的昼夜节律[46]。

1.2.2 光环境对动物定位系统的影响

许多生物利用光幕作为定位线索[47],如青蛙[48]和鸟类[49],但当光幕重建时,动物的定位系统就可能受到干扰。学者认为人工光环境干扰了动物原本利用月光进行导航的能力[47]。膜翅目、鳞翅目和鞘翅目昆虫利用天空中的偏振光进行导航[50]。候鸟则利用体内的磁感受器[51]和蓝光受体这两种“磁罗经”来导航[52],对光的波长和强度极为敏感[53],它们利用天空中的偏振光进行定位[54],并在黄昏或夜晚用光校准自己体内的生物罗盘[55]。光环境的变化将对动物的捕食、繁殖、生存、迁徙等行为产生影响[56]。但也有学者提出,光源的合理利用将有助于动物更好地导航、定位、捕捉猎物或交配[57]。

1.2.3 光环境对动物生长的影响

光可作为家禽养殖的一种显性的外源性兴奋剂[58],对家禽的生长,成熟和繁殖起积极作用[59]。学者对肉鸡偏好的光源条件进行研究后发现,合适的光强度[60]、光源[61]、波长[62]、闪烁频率[63]均有利于肉鸡体重的增加。已有学者对此方面研究进行综述[64]。

光环境对动物昼夜节律、定位系统、生长发育的影响已受到诸多关注。然而,不同波长的光、不同的光照强度、光暴露时间的长短等因素对动物的影响都还还有待进一步明确。

1.3 光环境对植物的影响

光是植物赖以生存的基础,它是植物体内一切生化反应的能量来源。植物的光合作用、向光性、光周期和分光灵敏性等都与光照直接相关[16,65]。植物中含有光敏色素[66]、隐花色素[67]、向光素[68]、UV-B 受体[69]等光受体,使得不同的植物对不同波长的光敏感性不同[70]。

研究发现,白光可促进作物中的[71,72]叶绿素的含量增加,还可提高菠菜嫩叶中维生素 C 含量[73]。黄光可提高葡萄[74]、莴苣[75]的叶绿素和类胡萝卜素的含量,使莴苣的可溶性蛋白和维生素 C 含量达到峰值[75]。红光可促进水稻幼苗的生长[76]和瓜类茎的伸长[77],种植业中使用红光照射植物,可有效增加作物的干物质量[78]、叶绿素含量[79,80]以及可溶性糖含量[80],同时提高光合速率[80,81]。蓝光可抑制水稻幼苗的株高[82]和促进番茄幼苗的生长[83],促进豌豆苗[84]、韭菜[85]中可溶性蛋白和维生素 C 含量的积累,使烟草光合速率提高而叶绿素含量下降[86]。由于红光与蓝光的光谱能量与叶绿

素的特征吸收峰一致[87]，因此，红光和蓝光组合照射常用于提高净光合速率以促进植物生长。研究发现，红白和红蓝白组合光下的番茄穴盘苗可溶性糖含量最高[88]。红蓝组合光照射可提高幼苗中可溶性糖含量[82,89]，也可导致芽苗菜硝酸盐的含量升高[90]。此外，光密度的高低也影响植物的生长发育。光密度减弱，烟草幼苗高度会增加，但叶片厚度、单位叶面积质量、干鲜比均下降[91]。

植物体中响应不同波长光的光敏感通道是十分敏感的，光环境的微小变化都可能导致植物在生理或形态建成方面发生变化，这也为研究光的生物效应留下了广阔的研究空间。但是迄今的研究多集中或局限于某个波段范围的光对植物生理生化指标的影响，对于特定波长的光与植物的作用以及特定波长光的光质效应缺乏深入研究[92]。

2　光环境模拟实验装备的研制现状

基于光环境对人、动物、植物均具有上述重要且广泛的影响，开展光环境生物学效应的研究，是完善物理环境生物效应研究体系的迫切需求。对于光环境的生物学效应研究，应当分别研究不同波长的光所产生的影响。因此，有必要在近紫外、可见光及近红外范围内实现单色光，且单色光的强度应达到现实光环境中对应波长的光强度。

然而，目前遇到的最关键的“瓶颈”就是：缺乏能够在一定波长范围内输出较高功率的单色光光源。现有的光学系统主要有以下三类：①可在较大光谱范围内生成单色光，但光源的功率小、光能量输出弱的仪器，主要为光学分析仪器[93—95]；②激光器可发射出特定波长单色光且光能量密度极大，在医疗、农业、材料加工等领域得以广泛应用，但其输出波长大多不可调谐或波长范围窄，且不能在较大面积内实现均匀辐照；③有些光源功率大，可在较大光谱范围内产生连续光谱，但未配备相应分光系统，无法生成单色光。用于光环境生物学效应研究的设备，需要单色光输出功率、均匀性等特性必须与太阳光谱中对应的单色光特性吻合，并且波长连续可调，光谱范围覆盖近紫外、可见光和近红外。但是，目前国内外尚无在此范围内输出百毫瓦甚至瓦级功率的单色光系统，且从单色仪输出的单色光均匀性也难以达到模拟太阳光均匀性的能力。

而且上述这些光学系统没有配备生物学培养装置，无法满足研究对象生存和繁育的需求。现有的商品化生物学光照系统，如人工气候箱，畜禽养殖系统等，虽然配备了基本的生物学培养装置，但其光照系统过于简单，不可能实现宽光谱单色光环境模拟。此外，目前的光环境模拟装置不配备完善的温湿度控制系统、CO_2 控制系统等，不能满足细胞、酵母、拟南芥、水稻、线虫、果蝇、小鼠等多种模式生物的生存及繁育要求，无法简单快捷地通过数字化的操作系统控制温湿度及气调，更不可能随时根据不同暴露对象的实验需求进行条件切换。

3　总结与展望

鉴于当前光环境生物学效应的开展尚缺乏精密的暴露装备，其发展当务之急应该是先构建光环境暴露的科学实验平台。

(1) 将所研制的装备用于研究不同波长光的生物学效应，为光环境生物学效应研究奠定必要的硬件基础，从而开拓中国的光环境生物学效应和机制研究新领域。

(2) 用于研究不同波长和强度的光化学反应，揭示光在大气、水、土壤中的化学动力学反应机理，推动光环境生物效应基础研究的发展。

(3) 为开展动植物光环境生物学效应研究提供实验条件，研究光环境变化对模式生物(如细胞、拟南芥、水稻、线虫、果蝇、小鼠等)的影响，有助于寻找不同物种、不同表型、行为、周期节律等对不同单色光的敏感性，从而揭示不同波长光对动植物的作用规律，在促进作物生长、驱虫避害、珍稀物种保护等方面具有推动作用。

(4) 进一步明确特定单色光或光波段对人类生理、心理健康等的影响，研究成果为环境评价、心理干预和临床治疗等提供科学依据。

(5) 开展光环境健康效应相关的评估、验证和研究工作，为制定中国光环境安全标准，预防光环境恶化等提供科学的依据、方法和支撑。对于建立和制定光环境政策、规范、法律、行政法规、制度具有重要的指导意义。

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Advances in the Biological Effect of Light Environment and Simulation Experimental Equipment

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[Abstract] Light is the basic condition on which human, animals and plants live. As a physical environment factor, the biological effect of light environment is of very important theoretical and practical value. Light environment has an important influence on human physiology, psychology and behavior; its effects on the circadian rhythm, positioning system, as well as growth and breeding of animals have attracted much attention. Simultaneously, light is the basis on which plants live, it is the source of energy for all the biochemical reactions of plants. The research progress of biological environment was reviewed, it was pointed out that the existing literature was limited to polychromatic light as the research object, the effect of specific wavelengths of light, exposure time and light quality were rarely researched. It was further illustrated that the key "bottleneck" of light environment simulation experiment equipment was lacking of a monochromatic light source with high power and a wide wavelength range. And there was no light environment simulation experiment equipment with biological culturing device. It's impossible to simulate monochromatic light in the laboratory. Therefore, it is urgent to build a scientific experimental platform for light environmental exposure. At the same time, the research directions of the biological effect of light environment and the applications of light environment simulation experiment equipment were prospected.

[Key words] light environment　bio-effect　simulation　equipment　advance