全球转基因作物的产量和销量

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摘 要 从 1994 年到现在,全世界转基因作物的种植生产和消费已经超过 20 年。转基因作物刚开始出现便立即被农民所接受。单单在 2013 年,全世界范围内包括棉花、玉米、大豆、油菜、甜菜和苜蓿在内的转基因作物种植面积已高达 1.75 亿 hm^2,有 14 个国家的转基因作物种植面积超过 50 万 hm^2。绝大多数转基因作物的两个典型优点是抗除草剂和抗虫。主要生产国的转基因作物普及率已经达到 90%。如今,转基因作物在发达国家的种植面积比发展中国家更大。截至目前,还没有关于人类消费转基因作物以及含转基因成分食品的数据统计,绝大部分(约 90%)的主要转基因作物被用作动物饲料,少数转基因作物,如木瓜、南瓜及甜玉米则被直接消费,油、淀粉、高果糖甜味剂、蔗糖和卵磷脂等来源于转基因作物的原料普遍被应用于食品产业。在美国超市,高达 70%的产品中含有转基因成分,很多其他国家的人们也在消费这样的产品,尤其是那些没有要求转基因标识的国家和地区。在许多国家,一些非政府组织经常散布关于转基因食物的谣言,以达到阻挠公众接受转基因食物和转基因作物商业化的目的。遗憾的是,政府决策者的决定常常基于政治考虑,而非出于转基因作物的重要科学意义。

关键词 转基因作物; 种植面积; 产量; 销量

中图分类号 Q 785 **文献标识码** A **文章编号** 1000-2421(2014)06-0120-13

从 1994 年卡基公司研发的莎弗番茄问世至今,转基因作物的种植和消费已有 20 年。随着我们对分子生物学的普遍认识,以及对冠瘿病病原菌农杆菌的作用模式的深入理解,基因工程技术应运而生。早在 20 世纪 50 年代,作物育种家就与实验室的科学家们联手改良作物性状。化学或辐射诱变、组织培养中的胚胎拯救、通过单个细胞产生整个植株的体细胞无性系变异的开发等技术都曾应用于作物的遗传改良[1]。通过对农杆菌的天然转基因机制的效仿和控制,我们可以在某个生物个体中引入新的基因或抑制它的已有基因的表达,这使我们获得了一个创造新表型的新方法或新手段。较早之前,人们可以通过植物组织培养由单个细胞产生整个植株。现在,将转化技术与之结合,人们得以将一个新的基因插入到植物基因组中,并在整个植株内表达这个基因。于是,作物基因工程学应运而生[2]。

公共机构和公司的科学家们开始思索并迫切希望将这种技术应用到提高作物的性状上来以满足农业生产的需要。在 20 世纪 80 年代初期,当该技术产生的时候,人口增长仍然处于不可控制的状态。6 亿人之中有 20%人口营养不良。人们对通过改良作物以消灭世界饥荒的新方法充满了殷切的期望,而后这个期望却落空了。难以置信的是,农民们很快便接受了转基因作物。2013 年,全世界包括棉花、玉米、油菜、大豆和甜菜在内的转基因作物种植面积高达 1.75 亿 hm^2,有 14 个国家的种植面积超过了 50 万 hm^2,这 14 个国家分别是:北美洲的美国和加拿大,南美洲的阿根廷、巴西、乌拉圭、玻利维亚和巴拉圭,亚洲的中国、印度、巴基斯坦和菲律宾,非洲的南非和布基纳法索,以及澳大利亚(图 1)。此外,还有 13 个国家在小范围内培育和种植转基因作物。这些国家中还包括欧盟的 5 个成员国,其中以西班牙和葡萄牙的生产量最大[3]。

在允许种植转基因作物的国家,被许可的转基因作物的种植已经接近饱和状态。转基因作物在这些国家的普及率达到 90%以上。2013 年,加拿大和美国的转基因油菜的普及率均高达 96%。在印度和中国,抗虫棉花的普及率在 2013 年分别为 95%

收稿日期: 2014-09-22
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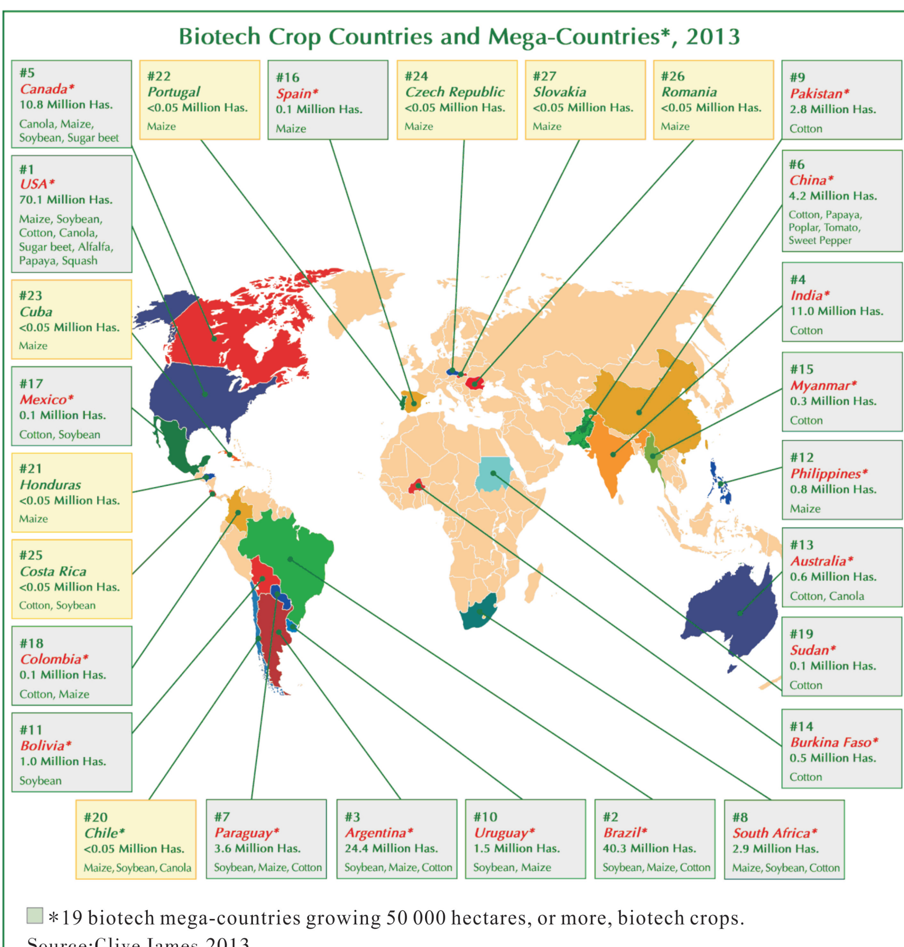
和 90%。转基因大豆在巴西和美国的普及率在 2013 年均超过 95%。由于巴西和美国是大豆的两个主要出口国，现在国际市场上非转基因大豆几乎难以寻觅。另一方面，整个转基因产业呈现出稳定的态势，除非有更多的国家愿意普及转基因作物的种植，或者有更多新的转基因作物或新基因被批准生产[4]。在孟山都公司普及抗马铃薯甲虫的转基因马铃薯的失败案例中，消费者的抵制是一个主要因素。从 1995 年引入到 2001 年撤回，主要快餐连锁店声称，他们将不会从农民手上购买转基因马铃薯[5]。

一些组织和网站反对转基因，这说明引进转基因作物及其来源的食品存在着许多问题和争议。在所有具有监管职能的国家（许多欠发达国家没有监管机构或尚未通过适当的法律），对农民实行转基因作物的监管程序通常被认为具有严格保障人类健康和环境的作用。不幸的是，“地球的朋友”和“绿色和平”这些所谓的“绿色”组织的恐吓战术以及有机食品产业的大肆宣传，使得政府在决定是否种植转基因作物时不得不忽略其科学意义而从政治方面考虑。与此同时，这些政府对于批准特定转基因作物的态度却十分开明，这也使得由转基因原料生产的食物得以进口和销售。然而，绿色组织们继而又要求给这些食品贴上“含转基因成分”的标签。这些标签本应作为一种关于植物育种方法的中立介绍，但由于被标识，加之有关转基因食品会影响人体健康的误导，使得这些标签在潜移默化中变成了对消费者的某种警示。最近发生的两个事件分别是印度的转基因抗虫茄子[6]和中国的转基因抗虫水稻[7]。尽管这两种作物均已得到科学机构的权威认证，但当地政府至今仍没有批准这些作物进入商品化生产。



种植面积超过 50 万 hm^2 的国家显示为“mega-countries”并标有星号。数据来自于参考文献[3] Countries that have more than 500 000 hectares are shown as “mega-countries” with an asterisk. From [3].

图 1　转基因作物种植国在全球的分布图

Fig. 1　World map showing the countries that grow GE crops

另外一个问题是基于对具有除草剂耐性的野草和对Bt毒蛋白产生抗性的害虫的考虑。这个问题相对而言并没有那么严重,因为人们更容易找到新的可行的解决办法。这是现代农业的典型问题,并且这些问题在转基因技术引进之前的几十年就已经存在。世界上绝大部分的转基因作物都是抗除草剂和抗虫的。在处理除草剂耐受的杂草问题时,科学家们使用了一种杂草交替控制的策略,其中包括开发一种兼具两种除草剂(如草甘膦和草铵膦[4])抗性的转基因作物。而耐受Bt蛋白害虫的出现,意味着我们需要开发一种新的转基因技术,例如表达昆虫特异的必需基因编码的双链RNA[8]。

1 全球生产的20年

1.1 转基因番茄是最早的转基因作物

第一例推向国际市场的转基因作物是由美国加州卡基生物技术公司研发的莎弗番茄FLAVR SAVR。莎弗番茄于1994年3月21日被推进市场[9]。这项基因工程是通过引入一个细胞壁软化酶—多聚半乳糖醛酸酶的编码基因的反义结构,以抑制该基因的表达。在这些番茄的包装上明确标注了该番茄是基因工程产品,并且公众也欣然接受了这种新事物,用这些番茄制成的番茄酱销往英国和美国。但是,由于产品和经销成本昂贵,这种新鲜番茄的销售并不乐观。在1996年至1999年间,销售量达1.8万罐,所有这些罐头均标注了原料为转基因番茄。这些产品得以成功商业化的原因是其降低了加工成本。然而,一位英国食品学家Arpad Pusztai博士在英国电视节目中宣称,用一种含有雪花莲凝集素基因的基因工程马铃薯饲喂小鼠后,小鼠出现若干健康问题,其中包括免疫系统缺陷和在相当于人类10岁时便出现生长萎缩。此消息一出,莎弗番茄的销量便大幅下降。Arpad Pusztai博士还断言这些问题的罪魁祸首就是产品研制的方法——基因工程,而无视他转入的基因和他用生马铃薯饲喂实验小鼠会带来的影响。随后,Pusztai对数据进行独立分析,但他并没有从中得到支持该结论的证据(对Pusztai事件的完整讨论见参考文献[10])。不幸的是,这次事件造成的损失已经由英国蔓延至美国。这种番茄酱不得不因此从超市下架,且不会再进入市场流向饭桌。

1.2 随后出现的2种非主粮转基因作物:西葫芦和木瓜

西葫芦是第2个被批准种植的转基因作物。它于1995年引入市场,但没有被标识为基因工程食品。这种西葫芦能够抵抗2种病毒——西瓜花叶病毒和小西葫芦黄花叶病毒[11]。这2种病毒的抗性通过传统育种转移至小西葫芦。但是由于西葫芦通常会感染第3种病毒——黄瓜花叶病毒,所以一种能够同时抵抗这3种病毒的转基因西葫芦诞生了。这项技术叫做病毒外壳蛋白保护,是将病毒的外壳蛋白基因转入植物。植物细胞中存在的病毒外壳蛋白能够抑制病毒的繁殖和扩散。这些转基因西葫芦品种在美国的种植面积仅2 000 hm^2。由于在不同的地区,西葫芦和小西葫芦可能会感染上除了上述3种以外的几种其他的病毒,所以这项技术的实际应用也十分有限。

紧接着被研制出来的作物是一种抗环斑病的木瓜。木瓜环斑病在世界的某些地区造成严重的危害[12]。这种转基因木瓜是夏威夷大学和康奈尔大学共同努力的成果,于1998年首次被研发成功。这项研究挽救了衰落的夏威夷木瓜产业,但这种木瓜的种植面积仅仅只有2 000 hm^2。该技术同样也是采用病毒外壳蛋白保护。随后,中国科学家重复了这个实验,这种转基因木瓜在中国的种植面积约为6 000 hm^2。

1.3 细菌基因的引入使主粮获得抗除草剂及抗虫的能力

据估计,在2013年,全世界转基因作物的种植面积达到1.75亿 hm^2[3]。其中超过90%的转基因作物种植在发展中国家的资源匮乏地区。尽管在美国,已有19种不同的转基因作物被批准种植,但目前世界上与转基因产业关联最大的无外乎2种基因(抗除草剂和抗虫)和4种主要作物(玉米、油菜、大豆和棉花)。抗除草剂和抗虫对于转基因作物商业化种植十分重要(表1),由于这些特性能够减少管理作物的必需投入,因而被称之为“投入性状”。抗除草剂基因使得对杂草的控制变得更容易,毒性除草剂的使用量亦大大降低,同时使得土地免耕或少耕。有别于化学杀虫剂对所有昆虫都具有毒杀作用,抗虫基因能够准确地作用于某些特定靶标害虫。同时,由于减少了杀虫剂的使用量,全世界农药年使用量也大幅度减少了。在世界的某些地区,工人在喷洒杀虫剂时缺乏保护,减少喷洒杀虫剂实质上也很大程度上避免了工人因直接暴露在杀虫剂中而导致的中毒事件。

抗除草剂性状最初由孟山都公司开发,用以简

化大豆和其他作物的管理。1998 年，孟山都公司的科学家们证明，大豆可以利用农杆菌系统进行基因的遗传转化[13]。几年后，孟山都公司成功将商标为农达的除草剂——草甘膦推向市场。这个除草剂通过抑制叶绿体酶 5-烯醇丙酮莽草酸-3-磷酸合成酶发挥作用，从而阻碍植物中芳香族氨基酸的合成。由于人类能够从日常的饮食中获得芳香族氨基酸，因此该除草剂对人体或其他动物是无害的。他们在农杆菌菌株中发现了一种对草甘膦不敏感的 EPSP 酶。该基因被恰当修饰并在植物中表达，使得转基因植物具有抗草甘膦的能力。在作物种植面积足够大时，通过喷雾使杂草吸收除草剂的方法已被认为是安全的。自此，主要的生物技术公司(拜耳作物科学、陶氏益农、杜邦/先锋、巴斯夫和先正达)都将抗除草剂目标集中于草铵膦、2,4-D 和磺酰脲[3]。在一些案例中，他们还开发了能够同时抗 2 种除草剂的作物。

表 1　2013 年种植在不同国家和地区的转基因作物的类型1)

Table 1　Types of GE crops grown in the different countries and areas under cultivation in 2013

国家或地区 Continent or country	面积/(×10⁴)hm² Area	作物 Crops
北美和中美洲 North and Central America		
美国 USA	7 010	抗除草剂大豆、抗虫/抗除草剂/抗虫－抗除草剂玉米、抗虫/抗除草剂/抗虫－抗除草剂棉花、抗除草剂油菜、抗病毒西葫芦、抗病毒木瓜、抗除草剂苜蓿、抗除草剂甜菜
加拿大 Canada	1 080	抗除草剂油菜、抗虫/抗除草剂/抗虫－抗除草剂玉米、抗除草剂大豆、抗除草剂甜菜
墨西哥 Mexico	1.14	抗虫棉花、抗除草剂大豆
洪都拉斯 Honduras	2	抗虫－抗除草剂玉米
古巴 Cuba	0.3	抗虫玉米
哥斯达黎加 Costa Rica	0.024	抗虫棉花、抗除草剂大豆(仅供种子出口)
南美洲 South America		
巴西 Brazil	4 030	抗除草剂大豆、抗虫玉米、抗虫棉花
阿根廷 Argentina	2 440	抗除草剂大豆、抗虫/抗除草剂/抗虫－抗除草剂 玉米、抗虫/抗除草剂棉花
巴拉圭 Paraguay	360	抗除草剂大豆
乌拉圭 Uruguay	150	抗除草剂大豆、抗虫玉米
玻利维亚 Bolivia	100	抗除草剂大豆
哥伦比亚 Colombia	10.9	抗虫棉花、抗虫玉米
智利 Chile	2.4	抗虫玉米、抗除草剂大豆、抗除草剂油菜(仅供种子出口)
亚洲 Asia		
印度 India	1 100	抗虫棉花
中国 China	420	抗虫棉花、抗病毒番茄、抗虫杨树、抗病毒木瓜、抗病毒甜椒
巴基斯坦 Pakistan	280	抗虫棉花
菲律宾 Philippines	80	抗虫/抗除草剂/抗虫－抗除草剂玉米
缅甸 Myanmar	30	抗虫棉花
非洲 Africa		
南非 South Africa	290	抗虫/抗除草剂/抗虫－抗除草剂 玉米、抗除草剂大豆、抗虫/抗除草剂/抗虫－抗除草剂棉花
布基纳法索 Burkina Faso	69	抗虫棉花
苏丹 Sudan	6.2	抗虫棉花
澳洲 Australia		
澳大利亚 Australia	64	抗虫/抗除草剂/抗虫－抗除草剂棉花、抗除草剂油菜、彩色康乃馨
欧洲 Europe		
西班牙 Spain	14.8	抗虫玉米
葡萄牙 Portugal	0.8	抗虫玉米
捷克共和国 Czech Republic	0.25	抗虫玉米
罗马尼亚 Romania	0.022	抗虫玉米
斯洛伐克 Slovakia	0.01	抗虫玉米
总计 Total	17 500	

1)数据来自参考文献[3]。HT＝除草剂耐受；Bt＝抗虫；HT-Bt＝除草剂耐受和抗虫的堆叠基因；VR＝抗病；FC＝花色 Data from [3]. HT＝Herbicide tolerance; Bt＝Insect resistance; HT-Bt＝Stacked genes for both HT and Bt; VR＝Virus resistance; FC＝Flower color.

抗虫作用是基于苏云金芽胞杆菌 *Cry1Ab* 基因的表达。该基因编码一种对鳞翅目昆虫有毒性作用的蛋白,可以用于杀死玉米蛀心虫欧洲玉米螟和棉花的主要害虫棉铃虫。孟山都在2003年将一个编码鞘翅目特异的内毒素蛋白 *Cry3Bb* 基因引入玉米中,旨在控制玉米根虫。为了提高植物中的表达量,达到足够多能够杀死目标害虫的内毒素蛋白,该基因像 *EPSP* 基因一样需要大量的基因修饰。其他的生物技术公司也跟风相继推出了抗各种鳞翅目害虫的 Bt 作物。

1)抗除草剂在四大作物——大豆、玉米、油菜和棉花中的应用。

1996年,抗除草剂大豆首次限量发放,并很快被农民所接受。大豆种植面积在1997年扩大到总种植面积的17%,1999年扩大到56%,2001年扩大到68%。到了2013年,种植面积在美国已经占93%。1997年,该大豆被加拿大和阿根廷引进,不久后又引入巴西。抗除草剂大豆(草甘膦、草铵膦和溴草腈耐受)现在在全世界种植超过8 450万 hm^2,占所有大豆种植面积的79%。在主要的大豆出口国美国和巴西,抗除草剂大豆占所有大豆种植面积的90%以上,造成国际市场上非转基因大豆的短缺[3]。这对动物饲养行业有着重大的影响。在一些国家,肉类和其他动物产品被贴上了"非转基因饲喂"的标签,但非转基因大豆的供应并不足以保障这个标签,为此英国的两个杂货连锁店放弃标识。2013年4月,乐购、Co-Op 和马莎宣称他们将不再需要非转基因饲喂的家禽。

孟山都研发的抗农达棉花,自1997年推出以来,其种植面积由10%迅速扩大到2001年的68%,到2013年达到82%。抗溴草腈的棉花也被研制出来了。相比之下,1997年推出的除草剂玉米推广速度慢一些,2002年种植面积达到10%,2010年稳定上升至60%,2013年在美国的种植面积占总面积的85%。油菜是加拿大的一种主要作物。抗除草剂油菜1995年首次在加拿大被批准种植,其推广非常迅速。在美国,油菜虽然不是主要作物,但其推广速度同样惊人。目前,有3种类型的油菜可用:抗草甘膦油菜、抗草铵膦油菜和一种抗 imidozolinine 除草剂的非转基因突变油菜。后者是由小孢子诱变和筛选所获得的[14]。目前在美国,抗除草剂苜蓿和甜菜的种植面积均在各自的总种植面积中占大部分。

2)抗虫在三大作物(玉米、棉花和油菜)中的应用。由孟山都公司推出的商品名为"棉铃卫士"的抗虫 Bt 棉花在1996年被引进,种植面积于1998年达到30%,2013年达到75%。该棉花能够抗3种鳞翅目害虫:烟草夜娥幼虫、棉铃虫和棉红铃虫。抗虫 Bt 玉米于1997年首次被种植,其种植面积在2年内升至25%。经过了2年的停滞,其种植面积又开始增加,至今在美国已占所有玉米种植面积的76%。2013年,全球转基因玉米种植面积达到5 740万 hm^2,占所有玉米面积的32%。然而,在美国种植的玉米中90%为转基因玉米,而且美国还是最大的玉米出口国。就像大豆一样,这意味着已经没有足够多的非转基因玉米可供饲喂国际市场中产出非转基因动物产品的动物。阿根廷、巴西、乌拉圭、洪都拉斯和南非也种植抗虫 Bt 玉米。在欧洲,虫害曾给在西班牙南部种植的玉米带来很大的压力,因此,西班牙也种植了大量的抗虫 Bt 玉米(10万 hm^2)。这是转基因作物在欧洲的第一次重要的推广。随后是一种既能抗虫又能抗草铵膦的转基因玉米,这种玉米也许能获得批准,但目前27个欧洲国家中至少有19个国家持反对态度。

3)除草剂和抗虫带来的增产效果。抗除草剂和抗内毒素蛋白基因的存在并不一定会提高产量。然而,抗除草剂油菜的产量却不断提高,这是由于该油菜的杂草管理模式更具有优势。植物育种家们一直将抗除草剂和抗虫的特性混合以形成新的基因型,以改良作物品种。没有这些转入的基因,类似的株系往往不能直接被利用,而农民们可能不得不种植以前的杂交作物。这意味着那些希望得到最好的种子的农民同时也接受了基因工程的特性。

1.4 欧洲的成果

在欧洲,只有2种转基因作物得到了商业种植的许可。欧洲食品安全局推荐过许多品种,但是欧盟委员会没有授权商业化生产。其中一个获批的品种是孟山都公司研发的抗虫玉米(称为 MON810)。这种玉米主要种植于西班牙和葡萄牙,并且只能用作动物饲料。MON810 玉米在法国、德国、希腊、奥地利、卢森堡和匈牙利都是被禁止的。第二例在欧盟被批准种植的转基因作物是一种被称为 Amflora 的马铃薯。该转基因马铃薯是由巴斯夫公司开发,用于生产纸用淀粉。该马铃薯于2011年开始在德国和瑞典种植。2013年1月,巴斯夫不再在欧盟种植转基因作物,2013年末欧盟法院取消了授权,双方对是否曾依法授予产生了争议[15]。在2014年,

根据另一个案件，欧盟考虑批准另一种抗虫玉米的商业化种植。该玉米是由杜邦公司开发，兼具抗虫和抗草铵膦的特性。如果各国反对种植转基因作物，那么即便是获得欧盟许可，各国也可以不予批准。英国至今没有种植任何转基因作物，但英国民众对转基因作物的反对已经不那么强烈了。例如，最近一项来自雷丁大学的研究表明：由于不允许种植转基因作物，农民失去了 0.6 亿～1.2 亿美元的收益[16]。

在决定是否批准转基因作物时，欧洲的权力部门并没有依据科学机构提供的建议。在检查相关数据之后，该组织反复声明支持在其他国家批准转基因作物种植。该组织进行了一系列评估，但并未得到与健康或环境相关的反对转基因作物种植或消费的理由。由此得出一个直接的结论便是，反对转基因是出于政治动机。此外，欧洲科学院科学咨询委员会在 2013 年 9 月发布了一份报告，称“截至目前，在全世界种植转基因作物 15 年以上，没有令人信服的证据可以证明这些作物给环境带来风险或对食品安全造成隐患”[17]。

1.5　我们何时得到对消费者有益的基因？

为了使公众认同转基因技术，我们有必要研发那些具有对消费者有益的转基因作物，向消费者呈现出转基因作物的明显优势。奇怪的是，公众并不认为减少杀虫剂的用量是有益的，这可能是因为公众还没有意识到作物喷洒杀虫剂是多么的频繁，对环境危害是多么的严重。比如，在欧洲，马铃薯需要喷洒 10～15 次的杀虫剂来对付晚疫病。对消费者有益的典范是黄金大米，即大米中含有充足的维他命 A，每天食用这种大米可以避免因维生素 A 缺乏引起的疾病。这对于将大米作为主要食物来源的人们来说尤为重要。

1）黄金大米。Ingo Potrykus 博士的创意逐渐变成现实。这种转基因大米引入并表达一种提高维他命 A 含量的基因，因此能够应对维生素 A 缺乏疾病，这种疾病多发于以大米为主粮的国家的贫困地区。最近一项研究[18]表明，100～150 g 黄金大米的米饭可以提供中国人推荐维生素 A 摄入量的 60%。据估计，儿童饮食中补充 20% 黄金大米，孕妇和乳母补充 10%，就能有效防御维生素 A 缺乏症。“立即开放黄金大米”社团发起了一项促进黄金大米商业化的国际运动。15 年来作为绿色和平组织一个有影响力的领导人，Patrick Moore 博士已经改变了他对转基因作物的看法。目前他进行着一些抗议和论坛活动，旨在终结绿色和平组织发起的阻止黄金大米的活动。绿色和平组织反对应用生物技术进行作物改良，而 Patrick Moore 博士想要揭穿他们关于黄金大米不仅没有价值而且损害人类健康和环境的谣言。第一个接受黄金大米的国家是菲律宾，菲律宾人绝大多数（80%）为罗马天主教。教皇弗朗西斯给予黄金大米的个人祝福起到了关键的作用。接受可能分为两个阶段：首先是消费其他地方种植的大米，然后是在菲律宾本土种植的黄金大米。

2）高油酸大豆油。2011 年，杜邦/先锋公司开始出售一种名为“Plenish”的转基因大豆。一年后孟山都公司准备推出一个类似的产品，商品名为“Vistive Gold”。用这些转基因大豆制成的大豆油具有高达 75% 的油酸含量和较低的饱和度，尤其是不饱和脂肪酸。这些大豆油相比那些富含不饱和脂肪酸的油具有更好的热稳定性，因此，更适合油炸和烘烤。目前这些转基因大豆油尚未在超市供应，但正在推向市场和食品加工厂[19]。这项技术涉及在一个去饱和酶基因（*fad*3）不活跃的情况下，利用抑制一个脂肪酸去饱和酶基因（*fad*2）的正链以使该基因下调表达来实现的。此外，孟山都公司的转基因大豆还抑制了一个 *fatB* 基因的表达，这个基因在叶绿体中编码一个硫酯酶，该酶从酰基载体蛋白释放 16∶0 和 18∶0 脂肪酸。在美国，该转基因大豆作为基因工程产品被批准种植。2014 年，其种植面积超过 20 万 hm^2。

3）不会变褐的苹果。Okanagan Specialty Fruits 是一个在英国、哥伦比亚和加拿大的公司，该公司在金冠苹果和澳洲青苹品种中抑制了多酚氧化酶的基因。这种苹果将推向市场并冠名为“北极苹果”，这大概是因为他们在切或咬（并放置）后仍然保持白色[20]。该产品所涉及的技术是基因沉默或 RNA 干扰，旨在削减制作袋装苹果切片的销售成本。现在为了防止褐变，公司花费相当大的成本给切面添加抗氧化剂。

4）植酸酶玉米。另一个已经进入生产的转基因作物是在种子中表达植酸酶玉米。中国农业科学院的科学家们在玉米种子中表达了一种真菌植酸酶[21]，目的是通过减少饲料中所必需的磷的用量，减少单胃动物，尤其是猪的浪费造成的磷污染。玉米和其他作物的种子以植酸盐的形式存储磷酸盐，但动物几乎没有植酸酶，因此，无法消化种子中储存

的植酸盐并释放出磷酸盐。该转基因作物已经获得生物安全委员会的批准,但尚未被种植。

1.6 哪些类型的机构开发转基因作物?

作物基因工程学是全世界共同的追求,而总部位于密苏里州圣路易斯的孟山都公司是第一个将转基因作物种子大量推向市场的领导者。自此,至少有5个其他的跨国公司也加入到这个领域[3]。孟山都研制出了转基因棉花、玉米、马铃薯、大豆、甜菜、番茄和小麦。总部设在蒙海姆的德国拜耳,研制了转基因棉花、玉米、水稻、大豆、甜菜、阿根廷油菜和波兰油菜。特拉华州威尔明顿市的杜邦公司,研制了转基因棉花、玉米、大豆和阿根廷油菜。总部位于德国路德维希港的巴斯夫,研制了转基因马铃薯、大豆和阿根廷油菜。总部设在印第安纳州印第安纳波利斯的陶氏益农公司,研发了转基因玉米、大豆和阿根廷油菜。总部设在瑞士巴塞尔的先正达公司,研发了转基因棉花和玉米。所有这些公司都在其他国家有分支机构,这些分支机构可能比在本国的总公司有更多的机会参与研发转基因作物。此外,许多跨国公司与小公司合作[3]开发上述的一些作物。合作也涉及到发展中国家的一些公司,如孟山都与印度 Mahyco 公司合资开发了抗虫 Bt 茄子。目前并不是所有上述的转基因作物都在市场上销售。这些转基因作物的主要特征是对广泛使用的除草剂的耐受性和源自苏云金杆菌 *Cry* 基因的抗虫性。

除了公司,许多公共机构也参与研发转基因作物。例如,中国有6个不同的公共机构参与开发转基因棉花、水稻、白杨、木瓜、番茄、胡椒和矮牵牛[3]。在巴西,“巴西农业研究公司”政府研究机构已收到转基因菜豆的商业化批准。该转基因菜豆能抗豆金色花叶病毒[22]。该技术依赖于对一个病毒基因的抑制,这个基因是病毒侵染豆科植物后进行复制的必需基因。该菜豆预计在2015年开始商业化。这是一个重大突破,因为豆类是拉丁美洲饮食一个非常重要的组成部分,尤其是这种应用生物技术的特色方法是由巴西开发的。

印度、缅甸和伊朗的公共机构同样活跃于转基因作物的研发领域。在美国,康奈尔大学和夏威夷大学参与研发了第一例抗病毒木瓜。美国农业部的 Ralph Scorza 博士研发了一种抗李痘病毒的转基因李[23]。这种李被称为 HobeySweet,已经被美国的3个监管机构(美国农业部、美国环境保护署和美国联邦药品管理局)所批准,但没有被种植,原因是李痘病毒并没有对美国造成影响。公共机构往往不具有将研发的产品推向市场化所必需的安全评价资金或技术。因此,公共机构常常向公司提供他们的研究,然后由公司进行后续的开发工作。

1.7 有多少转基因作物已经被开发?

根据 ISAAA 网站数据[3],27种不同的作物获得批准,其中包括19种食用作物、5种纤维或饲料作物和3种商业花卉作物。但并非所有的上述作物都可用于商业化。食用作物有:阿根廷油菜、菜豆、菊苣、茄子、玉米、甜瓜、木瓜、李、波兰油菜、马铃薯、大米、大豆、小西葫芦、甜菜、甘蔗、甜椒、烟草、番茄和小麦。非食用作物是苜蓿、棉花、匍匐剪股颖、亚麻和白杨。花卉作物则是康乃馨、矮牵牛和玫瑰。

与众不同的是,智利批准许多转基因作物的种植,但仅限于种子出口。由于智利位于南半球,与北半球的季节相反,以及它的植物检疫隔离,许多种子公司选择智利作为种子生产地。智利拥有庞大的种子产业,转基因种业则是其中的一个重要部分。转基因作物种植面积曾有所波动,但2010年达到2万 hm^2。智利种植或已种植的转基因作物有:油菜、玉米、大豆、水稻、红花、苜蓿、芥菜、大麦、桉树、亚麻、南瓜、向日葵、甜瓜、马铃薯、菠萝、甜菜、烟草、番茄、小麦和葡萄[24]。尽管抗除草剂和抗虫性是最重要的2个性状,一些其他性状也有研发,包括表达α淀粉酶的玉米、提高豆油含量、大豆油酸含量、红花中表达II型胰岛素原、提高红花中γ亚油酸含量、水稻表达人血清白蛋白、植酸酶油菜、红花牛酶、水稻乳铁蛋白、红花胰岛素的生产、玉米单克隆抗体的生产。

2 含有转基因成分的食物的消费状况

2.1 有多少人食用转基因作物和转基因作物来源的食品?

这个问题很难回答,尤其是在那些不要求标识和许多加工食品中含有转基因成分的国家。在全球,可能只有5%的转基因产品进入人类的食物链中,其余的都被用作动物饲料。事实上,在许多国家,种植或进口的转基因作物被严格限制于饲喂动物。由于许多产品缺乏可追溯性,商品和加工食品的国际贸易,以及一些国家的农民希望获得转基因种子并愿意非法种植转基因作物,我们可能永远无法回答这个问题。然而,既然没有证据表明转基因食品以任何方式损害人类健康,这可能是不必要考

虑的。如果我们假设 7.5 亿人每天都在食用转基因成分的食品，就算不作为主食，而是零食，这并不是不切实际的，那么就意味着一年多食用 2 500 亿餐。持续 10 年，就是食用 2.5 万亿餐。在这 2.5 万亿餐之中，尚没有任何食物中毒或其他意料之外影响报道。虽然转基因食品的反对者声称，没有标签将阻碍我们了解含有低水平毒素的转基因食品带来的长期影响，但毒理学家普遍认为，长期食用研究为食品安全提供了有价值的数据[25]，许多关于转基因作物的长期饲喂研究已经完成[26]。

2.2　不要求标识的国家

69 个国家要求转基因食品贴标识，但大多数国家没有这个要求。强制性标识是一个有争议的问题，通常从事生物技术产业人士持反对意见，而有机产业和各种非政府组织则予以支持。强制性标识通常被视为传播转基因作物及销售含转基因成分食品的一种阻碍，因为这些标识被公众视为某种警告[27]。那些反对强制性标识的人认为这种“警告”并不代表有结果表明含有转基因成分的食物会影响健康。赞成强制性标签的人则认为，我们应该遵循预防原则，并“警告”没有足够的证据表明这些食品是安全的。这些问题在一些国家引发了争论并遭到反对，另外一些国家还没有出现。例如在南美洲，只有 4 个国家需要标签：委内瑞拉和巴西（2004 年）、秘鲁（2010）和哥伦比亚（2012）。转基因大豆最大的生产地阿根廷、其他 3 个转基因作物产出国（巴拉圭、乌拉圭和玻利维亚）和智利，都没有要求标签的相关法律。

没错，美国人（和数亿其他人）每天都在吃转基因食品！

一个源自中国并在亚洲广为流传的传言是这样的：美国人种植的转基因作物全部出口到发展中国家，美国人自己从不吃这些作物生产的食品。这意味着转基因食品全部被发展中国家的人们所食用，而美国人自己是不吃这些转基因食品的。正如之前细述，美国人早在 1995 年便开始吃转基因番茄，至今已将近 20 年。据估计，多达 70％的美国加工食品可能含有转基因成分，如玉米淀粉、高果糖玉米糖浆、玉米油、菜籽油、大豆油、大豆粉、大豆卵磷脂或棉籽油[28]。在加工食品中转基因成分的总量可能低于 5％，但它是存在的。尽管含转基因成分的加工食品占有相当高的比例，但是在便利店中能够买到的转基因作物可能也只有夏威夷木瓜、西葫芦和甜玉米。在许多商店你可能找不到任何转基因生产的物品。然而，大多数美国人只隐约意识到他们在购买转基因食物，因为食物中含转基因成分没有被标记。类似的情况发生在加拿大和其他一些国家，这些地方没有为食品贴标签，但包含转基因原料的加工食品占比可能较低，这取决于当地人民的饮食习惯。

阿根廷、乌拉圭、巴拉圭、哥伦比亚是转基因作物（棉花、玉米和大豆）的 4 个重要产地。这些国家不需要食品标识。这些国家的情况与美国和加拿大相似。这 4 个国家的人口总和将近 1 亿。大豆油和大豆蛋白、改良玉米淀粉和高果糖玉米甜味剂都用于食品加工行业。阿根廷对欧洲出口的玉米粒和爆米花是可溯源的，这些玉米都是非转基因的（检测水平的 0.1％）。然而，用于制成“粥”（玉米面粉）、玉米片和其他供人类食用的特色产品的玉米品种的价格更高。因此，这些产品在阿根廷也是非转基因的，因为这些特殊的杂交种是不含转基因的。阿根廷没有批准转基因油菜，因为担心它会与白菜异交，并将除草剂耐受的性状传递给这个小麦主要杂草。除了棉花和玉米，哥伦比亚还种植了许多转基因花卉（比如蓝色康乃馨）。

当然，当植物的组成物质发生改变（例如黄金大米或高油酸大豆油）、可能会发生意想不到的健康问题（如一些人对某种蛋白质过敏）或感官属性发生变化（例如由挥发物引起的）时，美国、加拿大和上述 4 个南美洲国家也会要求标识。

智利也没有强制性标识和可溯源的要求，它是一个相对较小的转基因作物的生产国家。进口食品或用进口转基因原料制造的食品在便利店有售，但不进行标识。虽然转基因食品可用于出售，但仍有许多事件未得到立法机关的批准。关于生产，在约 2 万 hm^2 的土地上种植了许多不同的作物，但所有的种子必须用于出口。

墨西哥。据曾在比利时根特大学参与开发转基因技术的 Luis Herrera Estrella 博士介绍，墨西哥没有对转基因进行强制性标识，因此，含有或不含有转基因成分都不会被标识。关于制定法规，有人建议如果获得批准将严格效仿欧洲法规。转基因作物的种植仍然非常有限（玉米和大豆种植面积仅 20 万 hm^2）。在墨西哥，几乎所有的大豆都依靠进口，而黄玉米进口量则达到 1 000 万 t，这些作物都用作动物饲料。人类则食用白玉米（玉米饼、玉米粉蒸肉

等)。许多加工食品可能含有转基因的玉米淀粉或大豆油。一些白玉米也依赖进口,但大多是品质保持的和非转基因的。白玉米的种植者采取必要的预防措施,以避免由黄玉米花粉带来的交叉污染,而大部分黄玉米是美国的转基因作物。

在南非,对标识的争论仍没有结束。早期制定了标识法,但该法律有一些漏洞,会被食品公司钻空子。2012年提出了一项新的法律,但它还没有被采用。支持者和反对者继续大力游说政府官员。在南非,玉米制成的食物(如早餐麦片)都含有转基因玉米成分,以及所有大型食品公司生产的面包都含有转基因大豆产品[29](参见非洲生物安全中心发表的报告)。

2.3 含有转基因成分的食物在要求标识的国家的消费情况

在196个国家中只有69个需要标识以区分天然食品和含有转基因成分的加工食品。不幸的是,针对这些标识并没有统一的规定。首先,加工食品需要标识的最小比例不同。欧盟要求对0.9%以上进行标识,包括添加剂和调味料,但不需对转基因酵母菌株生产的奶酪和葡萄酒进行标识。澳大利亚、新西兰、沙特、巴西、委内瑞拉和俄罗斯的门槛为1%。韩国设置的限制为3%,另外一些国家和地区则使用5%(日本、泰国、南非、印尼、中国的台湾)。中国没有法定最低界限,而印度尚未解决这个问题。目前在这69个要求标识国家中,尚不清楚有多少个国家具有相关的机构以及足够的政治意愿来执行。

标识问题的困惑之处在于,在油、精制糖、淀粉或其他由转基因作物生产的产品中可能检测不到转入的基因或残留的蛋白质。因此,一些国家不再像其他国家那样要求标识由转基因大豆生产的大豆油。大多数国家没有标识,当然在包装上的文字会有差异。在美国,如果有人提出"联邦政府应该要求在食品上标注是否为基因修饰或生物工程",绝大多数人会表示同意[30],但在自发的民意调查中,当人们被问到希望在食物上看到什么额外的标签时,超过99%的人不会提到基因工程[31]。

尽我所知,没有针对各个国家到底消费多少转基因食品的评估。转基因作物的进口,或本国内非法使用转基因原料却没有标识的加工食品,都将混淆评估。对食品是否含有转基因成分进行分析并确保分析的可靠性仍然存在问题。

在欧洲有人吃转基因食品吗?当然!尽管限制了转基因作物的种植,但是许多转基因作物已经批准用于人类消费,如棉花、大豆、玉米、油菜和甜菜。据估计,60%的加工食品含有一些转基因玉米或大豆成分。产品中含有的转基因成分假如超过0.9%则必须进行标识,但是没有基因或蛋白残留的产品(油、淀粉、葡萄糖、果糖、葡萄糖、卵磷脂等)似乎规避了这个要求。据一个在比利时的组织——消费者组织研究和信息中心估计,在所有含转基因成分的食品中只有30%必须被标识[32]。绿色和平组织主张加工食品的"红""绿"名单中,绿色名单上几乎所有的食品都被标识为"有机"。并不是所有的标签都是直截了当的,标签可能会说"包含转基因成分",但它也可能说"根据现代生物技术加工工艺制造"。许多商店开始供应食用油和蛋黄酱。曲奇、薄饼、各种吸引孩子们的甜品、能量和蛋白质棒也开始供应。尽管欧洲的非政府组织强烈反对,但显然很多人都在消费含有转基因成分的食品。

巴西在2004年制定了标识法,是为数不多的几个(也可能是唯一一个)使用一种标志的国家,这个标志是一个黄色三角形和代表"转基因"的字母T。一些分销商额外添加了一句话:"由生物安全委员会批准"。消费者,尤其是那些不熟悉意思的,可能会将这个签注视为一个积极的声明,并优先选择这种产品。在超市发现转基因大豆为原料的产品(比如食用油)和转基因玉米制造的爆米花、玉米片和玉米罐头。含有玉米淀粉的小面包或其他产品也有供应和标识。Alexandre Lima Nepomucene博士认为,虽然许多产品被标识,但仍有许多确定含有或来源于转基因大豆的产品没有被标识,并且执行也不严格。

在日本,标签和消费的情况更为复杂。日本不允许农民种植转基因作物,但允许转基因作物的进口并要求对转基因成分超过5%的食品进行标识。油、糖、淀粉、甜味剂及其他不含转基因DNA或蛋白质的产品不需要标识。大多数国家能够接受在任意食品中使用转化技术,而日本却指定了可以使用含转基因原料的食品。

日本对命名有2个不同要求:(1)"GM",意味着它来自转基因作物,(2)"No Segregation",即它既包含转基因成分也包含非转基因成分,虽然事实上这些产品大部分为转基因,以及(3)非转基因的可选标签。虽然在商店里"No Segregation"是一种常见的标签,但却看不到"GM"标识。有33种产品需要标识"GM"或"No Segregation",其中大部分为含

有大豆、玉米、马铃薯、苜蓿或甜菜成分的加工食品。"No Segregation"标识应该是被公众所知的，但目前尚不清楚它的意思是否被消费者所理解。当被问及他们是否吃转基因产品时，消费者会否认，即使他们购买"No Segregation"标签的产品。有一段时间，Costco 超市销售来自夏威夷的转基因彩虹木瓜，并为每个木瓜贴上了"GM"标签。

印度有非常严格的标识要求。目前设定的最低比例为 0.1%。跨国公司的参与和关于负债的农民无法偿还贷款的谣言形成强烈的反差。然而，有足够的证据表明小农大大受益于转基因棉花的种植，但这些证据不被转基因技术的反对派所接受。印度开发了自己的抗虫 Bt 茄子，并完成了所有必要的转基因安全测试[6]。但是，由于各部门的报道之间相互冲突，使得商业化停滞于法庭之上。纳伦德拉·莫迪的新政府是否会采取不同的态度将拭目以待。在孟加拉国抗虫 Bt 茄子的即将商业化可能会使这一问题变得峰回路转。

孟加拉国还没有种植任何转基因作物，但已经批准了抗虫 Bt 茄子的商业开发。鉴于两国边境的互融性，无论政府最终批准与否，印度农民都很可能会接触到抗虫 Bt 茄子。海得拉巴美联社的生物技术研究所主任 Ananda Kumar 博士认为，目前在印度市场上并没有食物标注含有转基因成分。

马来西亚虽然有试验田，但还没有转基因的商业种植。食物必须贴上包含转基因的标签（见 2007 年以来的材料），但 Jennifer Harikrishna 博士认为该法案没有被执行。人们非常关注价格，并担心食品鉴别以判断是否含转基因成分会提高食品价格。由于标识法的应用，基因或基因的周边产品应该是可检测的。阈值尚未确定，但它可能高达 5%。

泰国的标识法规定最低为 5%，但措辞模糊，且不清楚多少必须标识。目前还不允许转基因作物的商业化生产，但众所周知，许多农民都在种植转基因棉花、大豆、玉米和木瓜。转基因玉米和大豆可以进口，但不能种植。泰国的情况也许是相当典型的：农民希望种植转基因作物，他们通常通过非法渠道从邻国获得转基因种子。但政府通过法律手段禁止种植转基因作物来挽回颜面，同时政府也没有能力检查不贴标签的食物是否含有转基因成分；而非政府组织仍旧用他们的行动告诉世人他们中毒了！欢迎来到这个真实的世界。

中国种植了数百万公顷的转基因抗虫棉花和抗病毒木瓜，但是还没有种植转基因玉米或大豆。包含转基因成分的食物需要标识，但最低界定值还未确定。因此，理论上，哪怕是微量的食物污染，甚至是不太可能残留转基因 DNA 或蛋白质的油或甜味剂，都必须被标识。转基因大豆油似乎是主要需要被标识的产品。一些油被标识为非转基因大豆来源，但它比较贵，而且似乎并不很受欢迎。由华中农业大学研发的抗虫转 Bt 大米的商业生产仍未获批准。所有的安全测试均已完成，但是政府还没有释放该品种的商品化。据中国媒体（中央电视台、上海日报等）在 2014 年春季和夏季的报道，该大学所在地武汉周围的农民被发现种植转基因水稻（确认为 BT63），并且转基因大米在超市出售。还不清楚这些农民是如何获得用以种植的转基因水稻种子，但在 7 月 30 日，政府机构销毁了 16 hm^2 的水稻。农民们获得的补偿是每公顷 100 美元[33]。

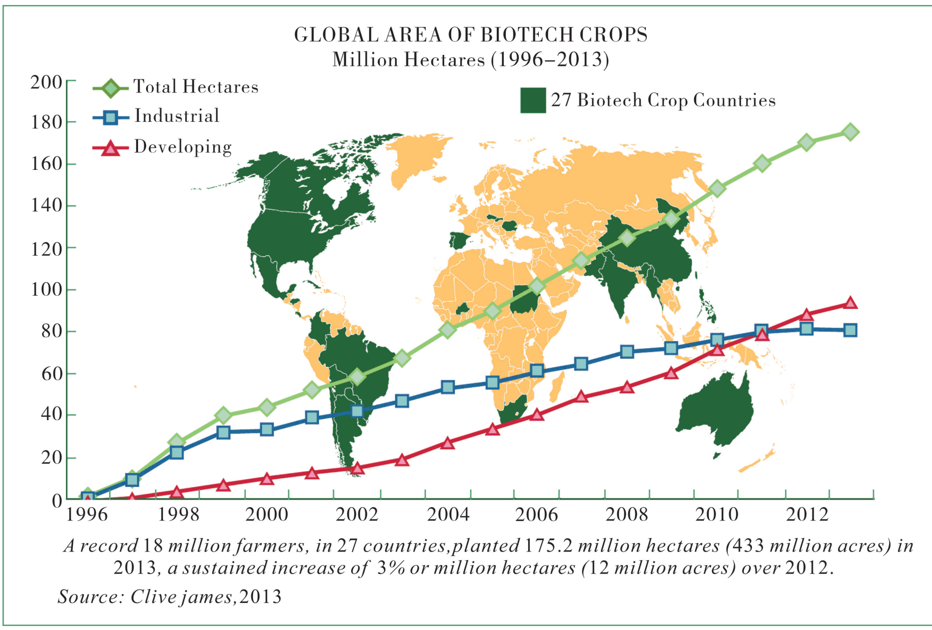
3　过时法规是否阻碍转基因的步伐？

基因工程是一个非常成功的技术，迅速被全世界允许种植地区的农民所接受。有充分的证据表明，源自转基因的食品并不会比传统的食品对人类健康更有害，并且种植这些作物也不会比传统农业生产给环境带来更多损害。相反，这些食品更具有营养价值（比如黄金大米、高油酸油），且转基因作物的种植更有益于农民的二次健康（少喷洒农药），更加环保，以及给许许多多的农民带来更多经济效益，带来更多实惠[34]。

尽管存在关于转基因食品消费的传言，但事实上美国人已经吃了 20 年的"转基因作物"[35]。过去的 10 年，10 亿人几乎每天都在吃含有转基因成分的食物。许多国家约 20% 的人仍然反对这一技术创新。他们拒绝科学发现，认为本来不存在的东西就是不好的。他们的世界观和他们的人生哲学不同于那些科学家。这 2 个派别的言论大相径庭，并且都不能说服对方。反对者对科学研究的结果不感兴趣，他们将努力说服政府官员禁止转基因作物和转基因食品。他们的世界观强调自由、多样性和生态平衡。当这个技术为他们提供便捷时，他们接受；而当这个技术与他们的世界观冲突时，他们反对。他们为他们眼中的真相而奋斗，并将努力说服各自的政府禁止基因改良食品。

世界上的穷人们有权利期望生物技术能给他们带来好处，并且在道德层面我们也有义务去推动这

项进程[36]。如果这项技术是为了实现养活本世纪末地球上的100亿人这么一个崇高的目标,那么政府关于管理转基因作物商业化种植的法规很可能会改变。可以理解,生物技术公司们正致力于向主粮中转入有全球意义的基因。政府批准的相关费用估计有5 000万美元[37]。这可能是一个生物科技公司的成本,但对于国家支持基础设施的公共机构来说成本则要低得多。在发展中国家,公共机构在开发新的转基因作物上处于前沿地位[38]。有趣的是,自2012年以来,发展中国家的转基因作物种植的总面积比经济发达国家更大(图2)。当转基因菜豆和转基因甘蔗投入生产,发展中国家的份额将迅速扩大。



参考自文献[3] From [3].

图2 全球发达国家和发展中国家的转基因作物种植面积(注意,后者在2012年超过前者)

Fig. 2 Global are of GE crops for both developed countries and developing countries (Note that the latter overtook the former in 2012)

所以我们要问:"谁会赋予小作物所需的基因,使其更有营养和具有抵抗害虫和病原体的能力?"主粮固然重要,但是良好的营养仍将依靠多样化和经济实惠的饮食。数十亿人仍将生活在小型家庭农场,吃着自己种植的主粮和蔬菜。生活在大城市的人们仍将依靠农民将他们的蔬菜运往当地市场。只有为这些农民提供最好的作物品种,我们才能根除饥饿和营养不良。分子遗传学家的研究已经表明,与传统植物育种相比,转基因植物的基因组没有发生异常变化[39]。组学研究和长期动物饲喂研究结果显示,与其他传统方法相比,这种遗传改良的方法不会引起任何担忧[40]。是时候让政府及其监管机构接受这一科学证据,并大大简化批复程序从而节约转基因作物批准的相关成本。世界上的穷人值得拥有更多。

致 谢 我要向许多科学家致谢,他们写信告诉了我在他们国家的转基因食物消费情况,包括:哥伦比亚的Norma Constanza Espinel;韩国的Youngsook Lee;智利的Loreto Holhuige;墨西哥的Luis Herrera Estrella;印度的P. Ananda Kumar;巴西的Alexandre Lima Nepomucene;泰国的Marlena Ketudat-Cairns;马来西亚的Jennifer Ann Harikrishna;英国的Christopher Leaver;阿根廷的Daniel Gonzalez;比利时的Daniel Demeyer和Lieve Geysen;以色列的Jonathan Gressel;意大利的Roberto Bollini和Sandro Vitale;日本的Nozomu Koizumi;中国的Hao Chen。

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Global production and consumption of genetically engineered crops

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Abstract Genetically engineered (GE) crops have been produced and consumed by people for 20 years, starting in 1994. Adoption of GE crops by farmers was astonishingly rapid and in 2013, GE varieties of cotton, maize, soybean, canola, sugarbeet, and alfalfa were grown on 174 million hectares around the world. Fourteen countries grew more than 500 000 hectares each. Two phenotypes represent the overwhelming majority of the GE crops: herbicide tolerance and insect resistance. Penetration has now reached 90% levels in major producing countries. There are now more hectares of GE crops in developing countries than in developed ones. There are no figures on human consumption of GE crops and foods containing GE ingredients. By far the largest proportion (possibly 90%) of the major GE crops is undoubtedly used for animal feed. Minor GE crops such as papaya, squash and sweet maize are consumed directly. Ingredients such as oil, starch, high fructose sweetener, sucrose and lecithin that are made from GE crops are used extensively in the food industry. In US supermarkets up to 70% of the products available contain GE ingredients. Such products are also consumed by people in many countries, especially those were there is no GE labeling requirement. The activities of NGOs, often using misinformation about GE foods, continue to slow the acceptance of GE foods by the public and the commercial production of GE crops in many countries. Decisions by policy makers are unfortunately often based on political considerations rather than on scientific criteria.

Key words genetically engineered crops; planting area; production; consumption

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The activities of NGOs, often using misinformation about GE foods, continue to slow the acceptance of GE foods by the public and the commercial production of GE crops in many countries. Decisions by policy makers are understandably, but unfortunately often based on political considerations rather than on scientific criteria.
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1 Introduction

Genetically engineered crops have been produced and consumed for 20 years, starting with the introduction of Calgene's FLAVR SAVR tomatoes in 1994. The technology was a natural outgrowth of our understanding of molecular biology in general and more specifically of the mode of action of the pathogen *Agrobacterium tumefaciens* in causing crown galls. Starting in the 1950s, plant breeders were collaborating with laboratory scientists to generate improved crop varieties. Chemical or radiation induced mutagenesis, embryo rescue in tissue culture, the exploitation of somaclonal variation via the generation of entire plants from single cells had all found uses in crop improvement[1]. The ability to mimic and control the natural gene transfer mechanism of *A. tumefaciens* led to an entirely new way of creating new genotypes by introducing entirely new genes or attenuating the expression of existing genes. In combination with earlier developments in plant tissue culture that permitted the growth of an entire plant from a single cell, transformation protocols allowed the insertion of a novel gene into the plant genome and its expression throughout the plant. The science of crop genetic engineering (GE) was born[2].

Scientists in public institutions and in companies immediately started thinking of ways that this technology could be used to improve crops to better serve the needs of agriculture. In the early 1980s, when the technology was developed, human population growth was still seen as being out of control. Furthermore, some 20 percent of the human population of 6 billion was malnourished. There were high expectations-which later proved to be misplaced-that this innovation in crop improvement could rapidly help to abolish world hunger. The adoption of GE crops by farmers was astonishingly quick and in 2013 GE varieties of cotton, maize, rapeseed (canola), soybean, and sugarbeet, were being grown on 174 million hectares around the world. Fourteen countries grew more than 500 000 hectares each: the USA and Canada in North America, Argentina, Brazil, Uruguay, Bolivia and Paraguay in South America, China, India, Pakistan

Received date:September 22, 2014
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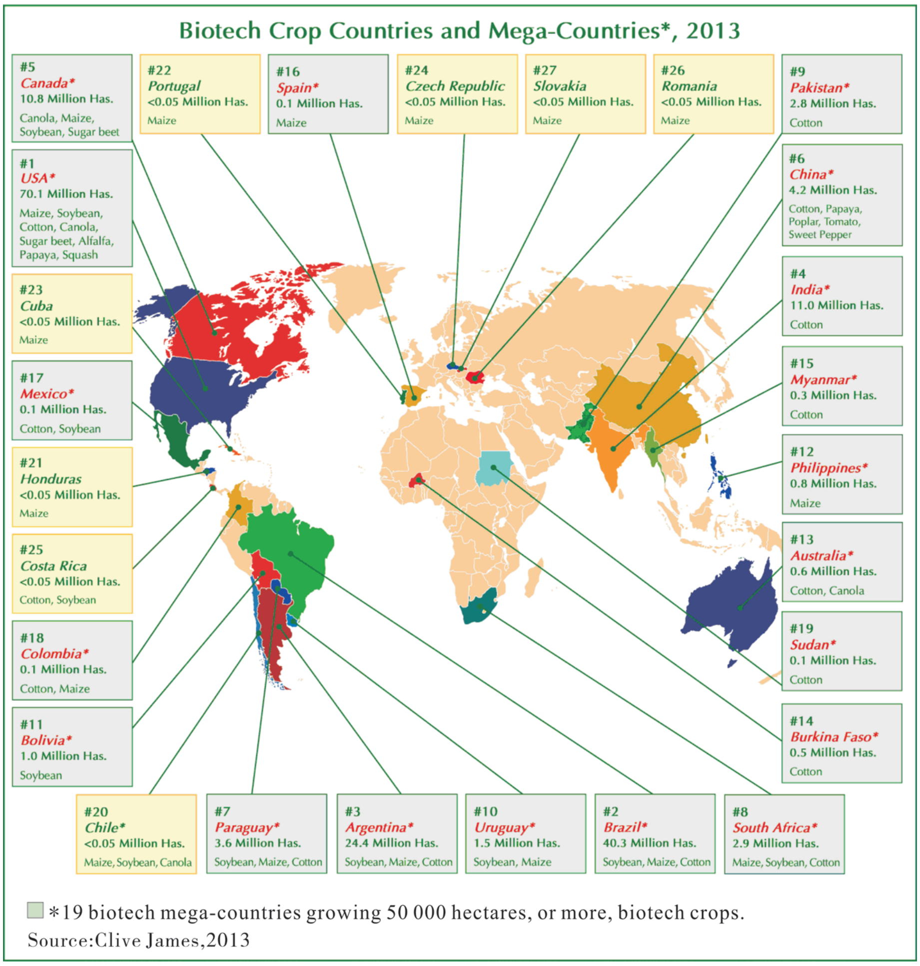
and the Philippines in Asia, South Africa and Burkina Faso in Africa, and Australia (Figure 1). Thirteen other countries cultivated them on smaller areas. This list includes five member states in the European Union, where Spain and Portugal are the biggest producers[3].

We have now arrived at a situation where the cultivation of those GE crops that have been approved has reached near saturation in the bigger countries that approved the planting of GE varieties. Adoption rates of GE crops in those countries are often 90% or more. GE canola had an adoption rate of 96% in 2013 in Canada and the US. Bt cotton had an adoption rate of 95% in India and 90% in China in 2013. Soybeans had adoption rates above 95% in Brazil and the USA in 2013. Because these two countries are the main soybean exporters, it is becoming increasingly difficult to buy non-GE soybeans on the international market. The other side of the coin of this rapid success is that the entire GE industry will plateau unless more countries are willing to adopt cultivation of GE crops and/or more crops and new genes are produced and approved. Many more gene/crop combinations have been approved[4], but these have usually not reached the market place. Consumer resistance is a major factor as has been documented for Monsanto's failure to get wide acceptance for its GE potato that was resistant to Colorado potato beetles. Introduced in 1995 it was withdrawn in 2001 when major fast food chains in the USA announced that they would not be purchasing the GE potatoes from farmers[5].

The introduction of GE crops and the foods derived from them has not been without problems or controversy as shown by the existence of numerous organizations and websites opposed to genetic manipulation. The regulatory process for the release of GE crops to farmers in all countries where the process functions (many less developed countries do not have regulatory agencies or have not yet passed the appropriate laws) is generally deemed rigorous as far as safeguarding human health and the environment are concerned. Unfortunately, the scare tactics of "green" organizations like *Friends of the Earth* and *Greenpeace* and lobbying by the organic food industry, have resulted in decisions made by governments about



Countries that have more than 50 000 hectares are shown as "mega-countries" with an asterisk. From [3].

Fig.1 World map showing thde countries that grow GE crops whether or not to plant GE crops based on political considerations rather than scientific ones. The same governments have been more liberal in their attitude towards approving specific transformation events so that foods with GE ingredients can be imported and sold. However, lobbying by the same green organizations have resulted in these foods requiring to be labeled as “containing GE ingredients”. Labeling combined with misinformation concerning the safety of GE foods for human health has resulted in these labels being perceived as warnings, rather than as neutral information about the method of plant breeding. Two recent examples of this phenomenon are the insect resistant eggplant (Bt-brinjal) in India[6] and insect resistant rice (Bt-rice) in China[7]. In spite of being approved by the science-based agencies in the respective countries, they have not been released for commercial production by their governments.

A second source of problems, less serious perhaps because they are more easily dealt with, concerns the emergence of herbicide tolerant weeds and Bt-toxin resistant insects. These are typical problems of modern agriculture and they arose several decades before GE technology was introduced. Herbicide tolerance and insect resistance are the two phenotypes that account for the vast majority of GE crops planted worldwide. With respect to weeds, there are alternate weed control strategies when herbicide tolerant weeds arise, including GE crops that are resistant to two different herbicides (glyphosate and glufosinate for example, see [4]). The appearance of insects that are resistant to Bt may require a novel GE approach, for example the expression of double stranded RNA encoded by specific essential insect genes[8].

2 Twenty years of global production

2.1 In the beginning there was the GE-tomato!

The first GM crop to be marketed anywhere in the world was the FLAVR SAVR tomato (*Solanum lycopersicum*) produced by the California biotechnology company Calgene, Inc. It was introduced on May 21, 1994[9]. The genetic engineering concerned the down regulation of expression by the introduction of antisense construct of the gene encoding the cell wall softening enzyme polygalacturonase. The boxes of tomatoes were clearly labeled as genetically engineered and the tomatoes were well received by the public. However, production and distribution costs were high and the sale of these fresh tomatoes was discontinued. Paste made from these tomatoes was sold in Britain and in the USA. Between 1996 and 1999, 1. 8 million cans were sold, all of them clearly labeled as derived from genetically engineered tomatoes. This product was a commercial success because of reduced processing costs. However, sales declined dramatically after Dr. Arpad Pusztai, a British food scientist, appeared on British television and asserted that rats fed potatoes genetically engineered with a snowdrop lectin gene had several health problems including immune system defects and stunted growth after a time period corresponding to 10 years of human life. He alleged that the problem was the method of production-genetic engineering-rather than the transgene or the fact that he was feeding raw potatoes to his experimental rats. Subsequently, independent analysis of the data found that they did not warrant the conclusions that Pusztai wished to draw from them. (For a complete discussion of the Pusztai affair see [10]). Unfortunately, the damage was done not only in Britain but also in the US. The tomato paste had to be removed from the shelves and no attempt was made to reintroduce it later.

2.2 Then came two minor crops, summer squash, and papaya a bit later

The second crop to be approved for planting was summer squash (yellow crookneck or zucchini, *Cucurbita pepo*). It reached the market in 1995 but was not labeled as genetically engineered. It was resistant to two viruses—Watermelon Mosaic Virus 2 and Zucchini Yellow Mosaic Virus[11]. Viral resistance was transferred to zucchini by breeding and, because squash is usually infected with a third virus, Cucumber Mosaic Virus (CMV), a GE squash resistant to all three viruses was developed. The technology used is known as viral coat protein protection, in which the gene for the coat protein of the virus is transferred to the plant gene. The presence of the coat protein in the plant cells suppresses the multiplication and spread of the virus. These GE squash varieties are grown in the US only on about 2 000 hectares. The usefulness of the technology is limited because in many areas squash and zucchini are subject to infection by several other viruses.

Developed somewhat later than the crops discussed below was papaya (*Carica papaya*) resistant to papaya ring spot virus, a serious papaya disease in certain parts of the world[12]. The project was a collaborative effort between the University of Hawaii and Cornell University and the GE papayas were first released in 1998. This development saved the Hawaiian papaya industry from certain decline, but the papayas are only grown on about 2 000 hectares. The technology used here was also viral coat protein protection. Chinese scientists repeated this effort and GE papayas are now grown in China on about 6 000 hectares.

2.3 Bacterial genes introduced into major crops make them tolerant of herbicides and resistant to insects

It is estimated that in 2013, 175 million hectares of GE crops were cultivated worldwide by 18 million farmers[3]. More than 90% of them were resource poor farmers in developing countries. Although GE events have been approved in 19 different crops in the US, by far the lion's share of worldwide GE activity concerns two types of genes: herbicide tolerance and insect resistance conferring in four crops (maize, canola, soybean and cotton). The importance of herbicide tolerance and insect resistance in commercially planted GE crops is clearly shown in Table 1. These traits are referred to as "input traits" because they reduce the inputs required for management of the crops. Herbicide tolerance genes allow for easier weed control and the use of less toxic herbicides. They also encourage no-till or low-till farming. Insect resistance genes allow for more precise targeting of insect pests as opposed to indiscriminate killing of all insects with chemical insecticides. They also reduce the number of insect sprays that are necessary thereby reducing the amount of insecticide that is used. Given that in many parts of the world spraying of insecticides is done without protection for the workers, reducing insecticide sprays has the substantial beneficial side-effect of reducing exposure of workers to insecticides and reducing accidental poisonings.

Herbicide tolerance was developed first by Monsanto

Table 1 Types of GE crops grown in the different countries and areas under cultivation in 2013[1)]

Continent country	Hectares/hm^2	Crops
North and Central America		
USA	70.1 million	HT soybean, HT/Bt/HT-Bt maize, Bt/HT/Bt-HT cotton, HT canola, VR squash, VR papaya, HT alfalfa, HT sugar beet
Canada	10. 8 million	HT canola, Bt/HT/Bt-HT maize, HT soybean, HT sugar beet
Mexico	114 000	Bt cotton, HT soybean
Honduras	20 000	Bt-HT maize
Cuba	3 000	Bt maize
Costa Rica	240	Bt cotton, HT soybean *Only for seed export*
South America		
Brazil	40.3 million	HT soybean, Bt maize, Bt cotton
Argentina	24.4 million	HT soybean, Bt/HT/Bt-HT maize, Bt/HT cotton
Paraguay	3.6 million	HT soybean
Uruguay	1.5 million	HT soybean, Bt maize
Bolivia	1.0 million	HT soybean
Colombia	109 000	Bt cotton, Bt maize
Chile	24 000	Bt maize, HT soybean, HT canola *Only for seed export*
Asia		
India	11.0 million	Bt cotton
China	4.2 million	Bt cotton, VR tomato, Bt poplar, VR papaya, VR sweet pepper
Pakistan	2.8 million	Bt cotton
Philippines	800 000	Bt/HT/Bt-HT maize
Myanmar	300 000	Bt cotton
Africa		
South Africa	2. 9 million	Bt/HT/Bt-HT maize, HT soybean, Bt/HT/Bt-HT cotton
Burkina Faso	690 000	Bt cotton
Sudan	62 000	Bt cottonAustralia
Australia		
Australia	640 000	Bt/HT/Bt-HT cotton, HT canola, FC carnation
Europe		
Spain	148 000	Bt maize
Portugal	8 000	Bt maize
Czech Republic	2 500	Bt maize
Romania	220	Bt maize
Slovakia	100	Bt maize
TOTAL	175 million	

1) Data from [3]. HT=herbicide tolerance; Bt=insect resistance; HT-Bt= stacked genes for both HT and Bt; VR=virus resistance; FC=flower color.

to make weed management in soybean and other crops easier. In 1988 Monsanto scientists demonstrated that soybean could be transformed using the *Agrobacterium* system[13]. For several years Monsanto had successfully marketed the herbicide glyphosate under the trade name Roundup™. This herbicide prevents aromatic amino acid biosynthesis in plants by inhibiting the chloroplast enzyme 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase. As humans get their aromatic amino acids from their diet this herbicide does not affect humans or other animals. They searched for an EPSP enzyme that was much less sensitive to glyphosate and found it in a strain of *Agrobacterium tumefaciens*. The gene was appropriately modified for expression in plants and the resulting GE plants were found to be tolerant to glyphosate. The herbicide could now safely be used as a post-emergence spray after crop and weeds had reached a sufficient size for the herbicide to be absorbed by the weeds. Since that time all major biotechnology companies (Bayer Crop Sciences, Dow Agrosciences, Dupont/Pioneer, BASF and Syngenta have made herbicide tolerant crops focusing on other herbicides including glufosinate, 2,4-D and sulfonylurea[3]. In some cases they developed crops tolerant of two herbicides.

Insect resistance is based on the expression of the *Bacillus thuringiensis Cry1Ab* gene that encodes a protein that is toxic to Lepidoptera. The goal was to kill the European stem borer (*Ostrinia nubilalis*) that attacks maize, and the cotton bollworm (*Helicoverpa armigera*), a major pest of cotton. In 2003 Monsanto introduced maize expressing the *Cry3Bb* gene that encodes an endotoxin protein specific for coleoptera and aimed at controlling the corn rootworm. As with the EPSP gene, considerable gene modification was needed to get high enough levels of expression in plants so that the endotoxin protein would be present at high enough levels to kill the target insect. Again, other major biotechnology companies followed suit and produced Bt-crops resistant to various lepidopteran pests.

1) Herbicide tolerance in the big four: soybean, maize, canola and cotton. Herbicide-tolerant soybeans became available to farmers for the first time in limited quantities in 1996 and adoption was extremely rapid. Use expanded to 17 percent of the soybean acreage in 1997, to 56 percent in 1999, and to 68 percent in 2001. By 2013 it occupied 93% of total acreage in the US. It was also introduced in Canada and Argentina in 1997 and somewhat later in Brazil. Herbicide tolerant soybeans (glyphosate, glufosinate and bromoxynil tolerant) now cover 84.5 million hectares worldwide and account for 79% of all soybeans produced. In the major soybean exporting countries-the USA and Brazil-herbicide resistant soybeans cover more than 90% of the soybean acreage, causing a shortage of non-GE soybeans on the international market[3]. This has major implications for the animal feeding industries. In some countries meat and other animal products are labeled as "not fed with GE feed", but the supply of non-GE soybeans is not abundant enough to guarantee this label, causing two grocery chains in the UK to abandon the label. In April 2013, Tesco, the Co-Op and Marks and Spencer announced they will no longer require poultry to be fed on GE-free feed.

Herbicide tolerant cotton became available in 1997 and rapidly expanded from 10% that year to 68% in 2001 and to 82% by 2013. Cotton has also been made tolerant of the herbicide bromoxynil. The adoption of herbicide tolerant maize, which became available in 1997 was much slower, reaching a plateau of 10% until 2002 and then steadily rising to 60% by 2010. In 2013 it occupied 85% of total acreage in the US. Herbicide tolerant canola was first approved in Canada in 1995 where it is a major crop and its adoption has also been very rapid there as well as in the US, where it is a minor crop. Three types are available: glyphosate tolerant canola, glufosinate tolerant canola and a mutant canola that is not GE and is tolerant to certain imidozolinine herbicides. The latter was made by microspore mutagenesis and selection[14]. Herbicide tolerant alfalfa and sugar beets now account for most of the acreage of those two crops in the USA.

2) Insect resistance in the big three: maize, cotton and canola. Insect-resistant Bt cotton was introduced in 1996, reaching 30% by 1998 and 75% in 2013. It protects against three Lepidopteron pests:the tobacco budworm (*Heliothis virescens*), the bollworm (*H. armigera*) and the pink bollworm (*Pectinophora gossypiella*). Bt maize was first planted in 1997 and within 2 years increased to 25% of acreage. After a 2-year lag it started increasing again and now occupies 76% of maize acreage in the USA. Worldwide GE maize covers 57.4 million hectares in 2013 and 32% of the maize area. However, 90% of the maize grown in the US is GE maize and the US is the biggest maize exporter. As with soybeans, this means that not enough non-GE maize is available on the international market for animal feed to produce non-GMO animal products. Bt maize is also grown in Argentina, Brazil, Uruguay, Honduras and South Africa. In the E U, Spain is growing significant quantities of Bt maize (100 000 hectares) because maize growing in southern Spain experiences considerable insect pressure. This is the first significant inroad of GE crops in the EU. A second GE maize resistant to insects and tolerant of glufosinate may be approved but at least 19 of the 27 EU countries objected to the approval.

3) Yield increases from herbicide tolerance and insect resistance. The presence of the gene that produces the glyphosate insensitive enzyme or the endotoxin protein does not necessarily result in higher yields. Nevertheless, canola yields have been shown to be consistently higher in herbicide tolerant canola because of better weed management compared to other weed management schemes. As plant breeders continue to improve crop varieties they always incorporate the herbicide tolerance and insect resistance characteristics into the new genotypes. Similar lines without these transgenes are not always available to the farmers who may have to plant older hybrids. This means that farmers who wish to get the best seeds must also accept the genetically engineered features.

2.4 Production in the European Union

Only two GE crops have ever been approved for commercial cultivation in the EU. The European Food Safety Authority (EFSA) has recommended the approval of many more events/varieties, but the European Commission has not authorized commercial production. One of the approved varieties is a pest-resistant maize (Bt maize) produced by Monsanto (known as MON810). This is grown mainly in Spain and Portugal and is only approved for animal feed. Cultivation of MON810 is banned in France, Germany, Greece, Austria, Luxemburg and Hungary. The second GE crop approved for cultivation in the EU is a potato known as the Amflora potato, which has been genetically modified by BASF to produce starch for use in making paper. It was grown in Germany and Sweden in 2011. BASF then withdrew from planting GE crops in Europe in January 2012 and in late 2013 the European Court annulled the authorization, arguing it had not been granted lawfully[15]. In 2014, following another court case, the EU considered approving the commercial cultivation of another insect-resistant maize produced by DuPont that is resistant to insects and tolerant of the herbicide glufosinate. Even if approved, individual countries may be able to opt out of the approval if they oppose growing the GE crop. Britain does not grow any GE crops at the moment but the opposition to GE crops has softened. For example, a recent study carried out by the University of Reading concludes that farmers are losing somewhere between 0.6 billion and 1.2 billion US $ by not being allowed to grow GE crops[16].

In deciding whether to approve GE crops, the authorities in the EU do not follow the advice of the science-based EFSA. After examining the relevant data, this organization has repeatedly stated its support for GE crops approved in other countries. It carries out its own assessments and has not found health or environment-related reasons to disapprove the planting or consumption of GE crops. This leads to the inevitable conclusion that the opposition to GMOs is politically motivated. In addition, the European Academies Science Advisory Council (EASAC) released a report in September 2013 that stated "The scientific literature shows no compelling evidence to associate such crops, now cultivated worldwide for more than 15 years, with risks to the environment or with safety hazards for food"[17].

2. 5 When will we get output genes?

To convince the public to buy into GE technology it will be necessary to produce GE crops with "output" traits that present a demonstrable advantage for the consumer. It is curious in this respect that diminished use of pesticides is not seen as a benefit by the public, probably because the public is unaware how often crops are sprayed. In Europe potatoes are sprayed 10 to 15 times against late blight fungus, for example. The poster child for the output trait approach is *Golden Rice*, rice that contains sufficient levels of pro-vitamin A so that a daily helping of rice will avoid vitamin A deficiency disease. This is particularly important for those populations that depend on rice as their main source of food.

1) *Golden Rice*. The brainchild of Dr. Ingo Potrykus is slowly moving forward. This GE rice expresses introduced genes that increase its pro-vitamin A content and will therefore address vitamin A deficiency (VAD) diseases commonly found among the poor in rice eating countries. Tests showing that the pro-vitamin A is readily available when the rice is fed to humans have been done. A recent study[18] showed that 100−150 g of cooked *Golden Rice* provided 60% of the Chinese recommended intake of vitamin A. Estimates suggest that supplementing *Golden Rice* for 20% of the diet of children and 10% for pregnant women and mothers will be enough to combat the effects of vitamin A deficiency. The *Allow Golden Rice Now*! Society is mounting an international campaign to promote the commercialization of golden rice. Dr Patrick Moore, an influential 15-year leader of Greenpeace has changed his mind about GE crops and is currently conducting a number of protests and forums with the aim to end the active blocking of *Golden Rice* by NGOs opposed to applications of biotechnology to crop improvement. He wants to debunk their claim that *Golden Rice* is either of no value or that it is a detriment to human health and the environment. The first adopter of *Golden Rice* may be The Philippines, an overwhelmingly (80%) Roman Catholic country. It is important in this respect that Pope Francis gave his personal blessing to *Golden Rice*. Acceptance may come in two phases: first consumption of rice grown elsewhere and then cultivation of rice in The Philippines.

2) High oleic acid soybean oil. In 2011, DuPont/ Pioneer started marketing a new GE soybean under the trade name *Plenish*. One year later Monsanto was ready with a similar product marketed under the trade name *Vistive Gold*. These oils have a high (75%) oleic acid content and are lower in saturated, but especially in poly-unsaturated fatty acids. These oils are more heat stable than oils that are rich in polyunsaturated fatty acids and therefore much better for frying and baking. The oils are not available in grocery stores but are being marketed to restaurants and to companies making processed foods[19]. The technology involves the down regulation of one fatty acid desaturase gene (*fad2*) using sense suppression in a background in which the second desaturase gene (*fad3*) is inactive. The Monsanto GE soybeans have an additional suppression of the *fatB* gene, encoding a thioesterase in the chloroplast that releases 16:0 and 18:0 fatty acids from acyl carrier protein. The GE soybeans were approved as a genetically modified product in the USA and more than 200 000 hectares were planted in 2014.

3) Non-browning apples. Okanagan Specialty Fruits, a company in British Columbia, Canada, has down-regulated the polyphenol oxidase genes present in Golden Delicious and Granny Smith apple varieties. They will be marketed as “Arctic Apples”, presumably because they stay white after cutting or biting into them (and letting them sit around)[20]. The technology involved is gene silencing or RNA interference. The goal is to cut the cost of apples that are sold in packages of apple slices. To prevent browning the companies now add antioxidants to the cut surfaces at considerable cost. (This barely qualifies as an output gene as the benefit to the public is not evident.)

4) Phytase maize. Another GE crop that may enter production is maize that expresses phytase in its seeds. Scientists from the Chinese Academy of Agricultural Sciences in Beijing, China, have expressed a fungal phytase in maize seeds[21]. The goal is to reduce phosphate pollution caused by the waste of monogastric animals, especially pigs, by reducing the amount of phosphate that needs to be added to the feed. Seeds of maize and other crops store phosphate as phytate (hexa-inositol phosphate), but animals have little phytase and therefore cannot digest the stored seed phytate to release phosphate. The GE crop has been approved by the biosafety committee, but has not yet been planted.

2.6 Which types of institutions develop GE crops?

The science that underlies crop genetic engineering was pursued simultaneously on both sides of the Atlantic, but Monsanto, based in St. Louis, Missouri, was the first to broadly market substantial quantities of seeds for GE crops. However, since then at least 5 other multinationals have entered the picture[3]. Monsanto has made GE cotton, maize, potato, soybean, sugar beet, tomato and wheat. Bayer Crop Science, with its headquarters in Monheim, Germany, has made GE cotton, maize, rice, soybean, sugar beet, Argentine canola (*B. napus*) and Polish canola (*B. rapa*). DuPont, headquartered in Wilmington, Delaware, has made GE cotton, maize, soybean and Argentine canola. BASF, headquartered in Ludwigshafen Germany, has made GE potato, soybean, and Argentine canola. Dow Agrosciences, headquartered in Indianapolis, Indiana has made GE maize, soybean and Argentine canola, and Syngenta, headquartered in Basel, Switzerland has made GE cotton and maize. All these companies have affiliates in other countries that may be more involved in making the GE crops, than the scientists who work in the country where the company is headquartered. In addition, many of these multinationals have partnered with smaller companies[3] to develop some of the crops listed above. Partnering has also involved companies in developing countries such as India where Monsanto made a joint venture with Mahyco to develop the Bt-eggplant. Not all the GE crops listed above are presently on the market. The main traits are tolerance to several widely used herbicides and insect resistance using *Cry* genes from *Bacillus thuringiensis*.

In addition to companies, many public institutions have been involved in creating GE crops. For example, in China six different public institutions have been involved in developing GE cotton, rice, poplar, papaya, tomato, pepper and petunia[3]. In Brazil, EMBRAPA the government research organization has received approval to commercialize the GE common bean (*Phaseolus vulgaris*) that is resistant to Bean Golden Mosaic Virus (BGMV)[22]. The technology used relies on the down regulation of a viral gene necessary for virus replication after the virus infects the bean plant.

Commercialization is expected to start in 2015. As beans are a very important part of the Latin American diet, this is a major breakthrough, especially as the unique biotechnology approach was developed in Brazil.

In India, Myanmar, and Iran, public institutions have also been active in GE crop development. In the USA, Cornell University and the University of Hawaii were involved in developing the first virus resistant papaya. Ralph Scorza of the United States Department of Agriculture (USDA) developed a GE plum (*Prunus domestica*) resistant to the plum pox virus[23]. The plum, known as HobeySweet has been approved by the three regulatory agencies of the US (the USDA, the Environmental Protection Agency and the Federal Drug Administration) but is not being planted because plum pox virus is not a problem in the US at this time. Public institutions often do not have the necessary funds or expertise to carry out all the regulatory work that is required to bring a crop to market. For this reason public institutions often license their technology to companies who then develop the invention further.

2.7 How many GE crops have been developed?

According to the ISAAA website[3], 27 different crops have approved events:19 food crops, five fiber or feed crops and three commercial flower crops. Not all of them are commercially available however. The food crops are:Argentine canola, common bean, chicory, eggplant, maize, melon, papaya, plum, polish canola, potato, rice, soybean, squash (zucchini), sugar beet, sugarcane, sweet pepper, tobacco, tomato and wheat. The non-food crops are alfalfa, cotton, creeping bentgrass, flax and poplar, and the flower crops are carnation, petunia and rose.

Chile is unique in that it permits the growing of many GE crops but only if the seeds are exported. Because of its position in the Southern Hemisphere with a reversal of seasons compared to the Northern Hemisphere, and its phytosanitary isolation, Chile is the site of choice by many seed companies to produce seeds. Chile has a substantial seed industry and GE seeds represent a significant component. The area has fluctuated but was 20 000 hectares in 2010. Chile cultivates or has cultivated GE rapeseed, maize, soybean, rice, safflower, alfalfa, *B. juncea*, barley, eucalyptus, flax, pumpkin, sunflower, melon, potato, pine, sugar beet, tobacco, tomato, wheat and grapes[24]. Although herbicide tolerance and insect resistance are the two most important traits, other traits have also been tested, including maize alpha amylase expression, soybean oil content, soybean oleic acid content, safflower expression of proinsulin2, safflower gamma linoleic acid content, rice expressing human albumin, canola phytase production, safflower bovine enzyme production, rice lactoferrin production, safflower insulin production, and maize monoclonal antibody production.

3 Consumption of foods containing GE ingredients

3.1 How many people eat GE crops and the foods derived from them?

This question is extremely difficult to answer, except for those countries that do not have labeling requirements and where ingredients from GE crops are present in many processed foods. On a worldwide scale, probably only 5% of what is produced finds its way into the human food chain, the rest being used as feed for animals. Indeed, in a number of countries the cultivation or import of GE crops is strictly limited to animal feed. Given the lack of traceability of many products, the international trade in commodities and processed foods, and the desire of farmers to get their hands on GE seeds and their willingness to plant them illegally in some countries, it may never be possible to answer this question. However, as there is no evidence that GE foods are in any way detrimental to anyone’s health, it may not be necessary. It is not unreasonable to suppose that 750 million people eat some foods with GE ingredients every day, if not for their main meal, then as a snack. Over a year that would be 250 billion meals. If they have been doing it for 10 years that would make it 2.5 trillion meals. There are no known food poisonings or other untoward effects from these 2.5 trillion meals. Although opponents of GE foods claim that the absence of labeling prevents us from knowing if low levels of toxins in GE foods have long-term effects, toxicologists generally agree that long-term feeding studies do not provide valuable data about food safety[25]. Nevertheless, many long-term feeding studies with GE foods have been done[26].

3.2 Countries that do not require labeling

Sixty-nine countries require labeling of GE foods, but the majority of countries do not have this requirement. Mandatory labeling is a contentious issue that is rejected by the biotech industry and supported by the organic industry and various NGOs. Mandatory labeling is seen as a deterrent to the spread of GE crops and the sale of foods with GE ingredients because such labels are seen as warnings by the public[27]. Those opposed to mandatory labeling contend that warnings are not warranted as no ill health effects have ever been documented for foods containing GE ingredients. People in favor of mandatory labeling believe we should be following the Precautionary Principle and warn people that there is not enough evidence that these foods are safe. In some countries the issue has come up and has been rejected, in others it has not yet come up. For example in South America only four countries require labeling:Venezuela and Brazil (introduced in 2004), Peru (2010) and Colombia (2012). Argentina, a big producer of GE soybean, Paraguay, Uruguay and Bolivia, three other GE crop-producing countries do not have labeling laws, neither does Chile.

United States of America. Yes, Americans (and hundreds of millions of others) do eat GE foods every day! A widespread urban myth originating in China and making the rounds in Asia goes like this: American farmers grow GE crops strictly for export to developing countries. Americans themselves don't eat the foods derived from these crops. The implication is that GE foods are good enough for the people of developing countries but not for Americans. As detailed above, Americans started eating GE tomatoes as early as 1994, 20 years ago. Estimates suggest that as much as 70% of U. S. processed food may contain an ingredient from a GE crop, such as maize starch, high fructose maize syrup, maize oil, canola oil, soybean oil, soy flour, soy lecithin, or cottonseed oil[28]. The total amount of GE ingredients in the processed food may be below 5%, but it is there. Despite this high percentage of processed foods that contain GE ingredients, the only commercially available GE produce in grocery stores may be Hawaiian papayas, summer squash/zucchinis and sweet corn (maize). In many stores you may not find any GE fresh produce items. However, most Americans are only vaguely aware that they are consuming GE foods because foods containing GE ingredients are not so labeled. The situation is similar in **Canada** and a number of other countries where foods are also not labeled, but the percentage of processed foods containing GE ingredients may be somewhat lower depending on the eating habits of the people.

Argentina, Uruguay, Paraguay and Colombia are four important GE food crop (cotton, maize and soybeans) producers that do not require labeling. The situation there is pretty much as it is in the USA and Canada. These four countries have a combined population of nearly 100 million. Soybean oil and soy protein, modified maize starch and high fructose sweetener derived from maize are used by the food processing industry. Argentina exports traceable identity-preserved flint and popcorn maize to Europe and these are GE-free (at the 0. 1% detection level). However, a much higher price is paid for these types of maize used to make "polenta" (maize flour), corn flakes and other specialty products for human consumption. As a consequence, these products are relatively GE-free in Argentina also, because these special hybrids are non-GMO. Argentina has not approved GE canola because of the fear that it would outcross with *Brassica campestris* and transfer its herbicide resistance to this important weed of wheat. Colombia grows many transgenic flowers (blue carnations) in addition to cotton and maize.

Countries like the USA, Canada, and the four South American countries named above do of course have a labeling requirement when there is a material change in the composition of the plant (e. g. *Golden Rice* or high oleic acid soybean oil), if an unexpected possible health problem could occur (e. g. a protein allergenic to some persons) or a change in the organoleptic properties (caused by volatiles, for example).

Chile also has no mandatory labeling and no traceability requirement, and is a relatively small producer of GE crops. Imported foods or foods made with imported GE ingredients are readily available in the grocery stores, but are unlabeled. Although GE foods are available, the legislature has not been able to agree on a list of approved events. With respect to production, many different crops are grown on about 20 000 hectares and all of the seeds must be exported.

Mexico. Dr. Luis Herrera Estrella who was involved in the development of the GE technology at the University of Ghent (Belgium) reported that Mexico does not (yet) have mandatory GM labeling, therefore, nothing is labeled either as being with GE or without GE ingredients. There are some proposals to introduce regulations that, if approved, will follow closely the European regulations. Cultivation of GE crops is still very limited (200 000 hectares of maize and soybean). Mexico imports nearly all of the soybeans that are consumed and imports about 10 million tons of yellow maize, which is used for animal feed. Human consumption (tortillas, tamales, …etc.) uses white maize. Many processed foods probably contain either starch or oil from transgenic maize or soybean oil. Some white maize is also imported but it is likely to be identity preserved and non-GE. Producers of white maize need to avoid cross-contamination by pollen from yellow maize, most of which is GE in the US, and therefore the maize growers take the necessary precautions.

In **South Africa**, the labeling debate still has not run its course. A labeling law was introduced early on, but was found to be widely ignored or circumvented because food companies found loopholes. A new law was proposed in 2012, but it has not as yet been adopted. Both proponents and opponents continue their heavy lobbying of government officials. In South Africa, foods made from maize (e. g. breakfast cereals) contain GE maize and all bread made by the big food companies in South Africa contains GE soybean products[29] (see the reports published by the African Centre for Biosafety).

3.3 Consumption of foods with GE ingredients in countries that require labeling

Sixty-nine countries out of a total of 196 now require labeling of whole and processed foods that have GE ingredients. Unfortunately, there is no uniformity in these regulations. First of all, the minimum percentage above which processed foods have to be labeled differs. The European Union requires labeling above 0. 9%, including additives and flavorings, but exempt products like cheese and wine made with GE strains of yeast. Australia, New Zealand, Saudi Arabia, Brazil, Venezuela and Russia use a 1% threshold. South Korea sets the limit at 3%, and a number of other countries use 5% (Japan, Thailand, South Africa, Indonesia, Taiwan). China has no legal minimum limit and India has not yet been able to resolve the issue. Of the 69 countries that have labeling requirements, it is not clear how many have the institutional capacity and political will to enforce that labeling requirement.

The labeling issue is confounded by the problem that the transgenes themselves (DNA) or the proteins they encode may not be detectable in the oils, refined sugar, starch or other products derived from the GE crop plants. So, in response, some countries do not require that oil from GE soybeans be labeled, whereas other countries do. Most countries do not have a logo, and of course the wording differs as does the placement of the wording on the package. If, in the USA, people are asked if "the federal government should require labels on food saying whether it has been genetically modified or bioengineered", an overwhelming majority agree[30], but in unprompted polls, when people are asked what additional labeling they would like to see on food more than 99% do not mention genetic engineering[31].

There are to the best of my knowledge no estimates of how much GE food is consumed in each country. Any estimate would be confounded by the importation of GE crops or processed foods that are not labeled and by the illegal use of GE ingredients in processing in the country itself. There remains the issue of assaying foods for the presence of GE ingredients and ensuring that these assays are reliable.

Does anyone eat GE foods in the **European Union**? Certainly! In spite of the restrictions on growing GE crops (see above) many transgenic events have been approved for human consumption in cotton, soybean, maize, canola and sugar beet. It is estimated that 60% of processed foods contain some maize or soybean ingredients. Products have to be labeled if they contain more than 0. 9% GE ingredients, but products without genes or proteins (oil, starch, glucose, fructose, dextrose, lecithin…etc) appear to escape this requirement. OIVO (Research and Information Center of Consumer Organizations), an organization in Belgium estimates that only 30% of the foods that contain GE ingredients will have to be labeled[32]. Greenpeace maintains "Red" and "Green" lists of processed foods. Nearly all the foods on the green list are also labeled "organic". Not all labeling is straightforward:the label may say "Contains GE ingredients" but it may also say: "Made according to modern processes of biotechnology", apparently. Cooking oils and mayonnaise appear to be available in many stores. Cookies, crackers, various sweet confections that appeal to children, energy and protein bars are also available. In spite of the very vociferous opposition of NGOs in the EU, foods with GE ingredients are obviously consumed by many people.

Brazil instituted its labeling law in 2004 and is one of the few countries (the only one?) that uses a logo: a yellow triangle with the letter T for "transgenic". Some distributors add an additional statement that says "Approved by the Biosafety Committee" Consumers, especially those unfamiliar with the meaning, may see this endorsement as a positive statement and give preference to this product. In the supermarkets one finds products based on GE soybean (such as cooking oil) and based on GE maize including popcorn, corn flakes, and canned maize. Biscuits and other products that contain maize starch are also available and labeled. A number of products are labeled, but many which surely must contain GMO soybeans or products derived from them are not labeled and enforcement is lax according to Dr. Alexandre Lima Nepomucene.

In **Japan** the labeling and consumption situation is more complex. Japan does not permit its farmers to grow GE crops, but it does import them and requires labeling of food products that contain GE ingredients if the level is above 5%. Oils, sugar, starch, sweetener and other products that do not contain either transgene DNA or protein do not need to be labeled. Most countries permit certain transformation events to be used in any food, but Japan specifies the foods in which GE ingredients can be used.

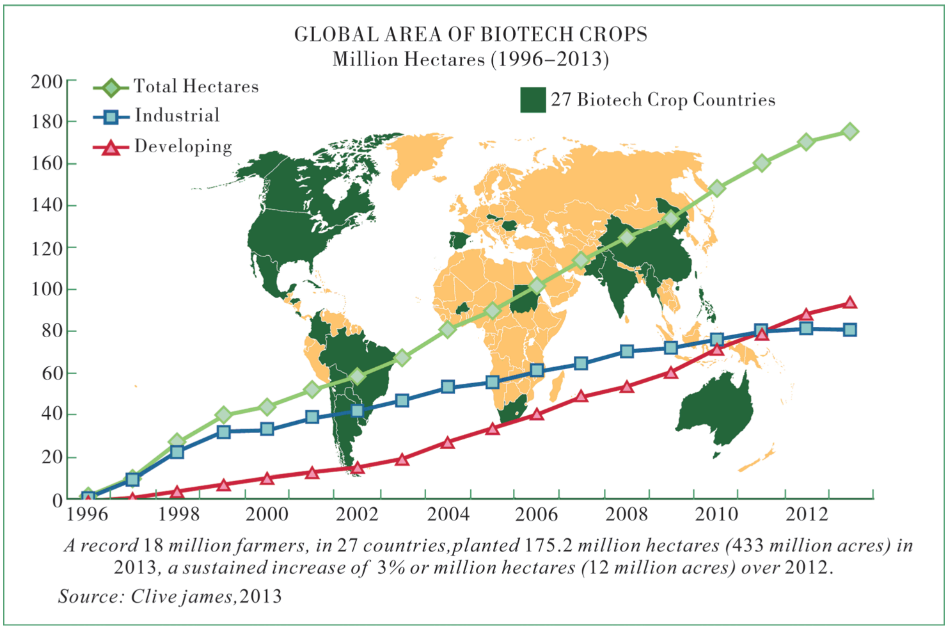
Japan has two different required designations: (1)*GM*, meaning that it has been identity preserved, (2)*No Segregation*, meaning that it contains both GE and non-GE ingredients although in practice these products are mostly GE, and (3) an optional label of Non-GM. In the store one sees no *GM* labels, although *No Segregation* is a common label. Labels of *GM* or *No Segregation* are required for 33 products most of which are processed foods containing ingredients from soybeans, maize, potatoes, alfalfa or sugar beets. The *No Segregation* label is supposed to inform the public but it is not clear that its meaning is understood by the customers. When asked if they eat GM products, consumers say they do not, even though they buy products with the *No Segregation* label. For a short period of time GE Rainbow papayas from Hawaii were being sold by Costco and each papaya carried a *GM* sticker.

India has very strict labeling requirements. The minimum percentage is presently set at 0.1%. The involvement of multinationals and rumors that indebted farmers could not repay their loans have fed fierce opposition. Nevertheless there is sufficient evidence that smallholders have substantially benefitted from GE cotton cultivation but this evidence is not accepted by groups opposed to GE technology. India developed its own Bt eggplant (brinjal) and all the requisite safety tests have been done[6]. However, commercialization is held up in the courts because of conflicting reports from various ministries. Whether the new government of Narendra Modi will take a different stance remains to be seen. The issue may be forced by the impending commercialization of Bt eggplant in Bangladesh.

Bangladesh does not grow any GE crops yet but has approved Bt brinjal for commercial development. Given the porous nature of the border between the two countries it is likely that Bt brinjal will reach Indian farmers whether the government ultimately approves it or not. According to Dr. Ananda Kumar, the Director of the Institute of Biotechnology in Hyderabad, A. P. no foods labeled as containing GE ingredients are presently in the marketplace in India.

Malaysia has no commercial growing of GMOs although experimental plots are present. Foods have to be labeled as containing GE ingredients since 2007, but the act is not enforced according to Dr. Jennifer Harikrishna. People are very price conscious and fear that identity preservation will raise food prices. The genes or the products of the genes should be detectable for the labeling law to be applied. The threshold has not yet been set, but it may be as high as 5%.

Thailand also has a labeling law with a 5% minimum, but the wording is muddled and it is not clear that much would have to be labeled. Commercial production of GE crops is not allowed as yet but it is widely known/rumored that many farmers grow



Note that the latter overtook the former in 2012. From [3].

Fig.2 Global are of GE crops for both developed countries and developing countries

GE cotton, soybeans, maize and papayas. Officially, GE maize and soybean can be imported, but these cannot be planted. This may be rather typical: the farmers want GE crops and they obtain seeds through illegal channels, often from neighboring countries; the government saves face by officially forbidding planting of GE crops; there is no capacity to check whether food that is not labeled contains GE ingredients and the NGOs continue their campaign telling people they are being poisoned! Welcome to the real world.

China grows millions of hectares of GE Bt-cotton as well as virus-resistant papayas, but no maize or soybeans as yet. Foods containing GE ingredients have to be labeled, but a minimum threshold level has not been established. So, theoretically, foods with even the tiniest amount of contamination would have to be labeled, even oils or sweeteners unlikely to contain either DNA or protein from transgenes. Soybean oil appears to be the main product that is labeled. Some oil is labeled as not derived from GE soybeans, but it is quite a bit more expensive and it does not appear to be very popular. Commercial production of Bt-resistant GE rice made at Huazhong Agricultural University has still not been approved. All the safety tests have been done, but the government has not released the new varieties for commercial production. According to reports in the Chinese media (CCTV, Shanghai Daily and others) in spring and summer of 2014, farmers around Wuhan where the university is located were found to be growing GE rice (identified as BT63) and GE rice was for sale in the supermarkets. How the farmers obtained the rice seeds for planting is far from clear, but on July 30th government agents destroyed 16 hectares of the rice. The farmers were apparently compensated $ 100 per hectare[33].

4 Are outdated regulations the bottleneck to moving forward?

Genetic engineering has been an amazingly successful technology, rapidly adopted by farmers all over the world where they were permitted to do so. There is more than sufficient evidence that the foods derived from them are not harmful to human health any more so than conventional foods, and that cultivating these crops is not more harmful to the environment than conventional agriculture. To the contrary, the foods can have nutritional benefits (*Golden Rice*; high oleic acid oil) and GE crop cultivation can have secondary health benefits for farmers (less spraying of pesticides), benefits for the environment, and financial benefits for large and small farmers[34].

In spite of the urban myths about GE food consumption, Americans have been eating “GMOs” for 20 years[35]. Foods with GE ingredients have probably been eaten nearly every day by 1 billion people for the past 10 years. Still, some 20% of people in many countries oppose this technological innovation. They reject the scientific findings and do so for existential reasons. Their view of the world and their life philosophy differ from those of scientists. These two groups talk at cross purposes and cannot convince each other. Opponents are not interested in the outcome of scientific studies and they will work hard to convince government officials to ban GE crops and GE foods. Their world view emphasizes freedom, diversity, ecological balance. They accept technology when it is convenient and reject it when it conflicts with their world view. They will fight for the truth as they see it. And will work hard to convince their respective governments to ban genetic modification of food.

The poor people of this earth have a right to expect that the benefits of crop biotechnology will reach them too, and we have an ethical obligation to make sure that this happens[36]. If the technology is to achieve the lofty goal of helping to feed the 10 billion people who are likely to inhabit the earth by the end of this century, much may have to change in the government regulations that govern the commercial planting of GE crops. Understandably, biotechnology companies are limiting themselves to the big staple crops with input genes that are useful all over the world. The costs associated with government approval have been estimated to be 50 million dollars[37]. This may be the cost for a biotech company, but the incremental costs for public institutions where the state supports the infrastructure are much lower. In developing countries, public institutions are at the forefront of creating new GE crops[38]. It is interesting in this respect that since 2012, GE crops have been planted on larger total area in developing countries than in economically advanced countries (Figure 2). When GE common bean and GE sugarcane come online the share of the developing countries will rapidly expand.

So we need to ask, “Who will endow the minor crops with the genes they need to be more nutritious and fight off pests and pathogens?” Staples are important, but good nutrition will continue to depend on a diversified and affordable diet. Several billion people will continue to live on small family farms eating the staples and vegetables they grow themselves. People living in large cities will continue to rely on truck farmers who bring their vegetables to local markets. Only by providing these farmers access to the best crop varieties will we be able to come close to eradicate hunger and malnutrition. Molecular geneticists have shown that nothing out of the ordinary-compared to traditional plant breeding is happening with the genomes of GE plants[39]. Neither the omics studies, nor the long-term animal feeding studies have raised any concerns about this method of genetic improvement compared to other methods[40]. It is time for governments and their regulators to accept this scientific evidence and greatly reduce the documentation and thus the cost associated with approval of GE crops. The poor people of the earth deserve nothing less.

Acknowledgement: I thank the many scientist friends who wrote to me about the consumption of GE foods in their respective countries. Colombia, Norma Constanza Espinel; Korea, Youngsook Lee; Chile, Loreto Holhuige; Mexico, Luis Herrera Estrella; India, P. Ananda Kumar; Brasil, Alexandre Lima Nepomucene; Thailand, Marlena Ketudat-Cairns; Malaysia, Jennifer Ann Harikrishna; Great Britain, Christopher Leaver; Argentina, Daniel Gonzalez; Belgium, Daniel Demeyer and Lieve Geysen; Israel, Jonathan Gressel; Italy, Roberto Bollini and Sandro Vitale; Japan, Nozomu Koizumi; China, Hao Chen.

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