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微波辐照对小米印度谷螟卵灭除效果及品质影响的研究

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摘　要:[目的]印度谷螟(*Plodia interpunctella*)在小米中繁殖能力很强,对小米的破坏性很大,主要使用的化学药剂熏蒸防治方法易引起环境污染、药剂残留、印度谷螟的抗药性增强等一系列的问题。微波技术可用于防治粮食虫害且绿色环保。本研究旨在获得微波辐照对小米印度谷螟卵灭除效果及品质影响的研究。[方法]采用微波160、320、480、640和800 W的功率和5、10、15、20、25和30 s的时间辐照小米,通过测量小米0、3、5、8、10 cm深度的印度谷螟卵的存活率和小米温度,观测微波辐照在小米不同深度的灭卵效果和微波在小米中的传播规律。同时测量微波辐照后小米的黏滞特性、色度和含水率,观测微波辐照对小米品质的影响。[结果]相同功率和时间的微波辐照小米,深度越小处印度谷螟卵存活率越低,灭卵效果越好。160W30s和320W15s低强度微波直接辐照印度谷螟卵,卵的外部形态基本保持不变,无法灭卵;采用800W15s、640W20s、480W25s微波辐照能有效消灭小米0 cm(平铺)处卵;800W20s、640W25s、480W30s辐照能有效消灭小米3 cm深度处卵;800W30s高强度微波辐照后,小米5 cm深度卵的存活率为25%,8、10 cm深处卵的存活率仍相对较高,灭卵效果不佳。相同功率和时间的微波辐照小米,深度越大处小米内部温度越小,且小米内部温度随深度以指数规律衰减。640W30s微波辐照后小米峰值粘度和衰减值升高,480W25s、800W25s和800W30s微波辐照后小米的糊化温度升高;除800W30s高强度处理外,微波辐照对小米色度无明显影响;微波辐照后小米含水率降低,为小米储藏创造了更好的条件。640W30s微波辐照提升了小米的食用品质,而800W25s和800W30s高强度辐照降低小米品质。[结论]小米深度是影响微波辐照灭卵效果的重要因素,微波辐照灭卵小米深度不宜超过3 cm。采用640W30s微波辐照厚度3 cm内的小米,既能有效灭卵又能提升小米的品质。本研究为微波技术防治小米储藏虫害,减少经济损失提供科学依据。

关键词:微波; 印度谷螟卵; 深度; 灭卵效果; 小米品质
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“神农五谷,粟居第一”,小米与其它谷物相比,富含蛋白质和脂肪。此外,小米中也含有一般谷物所不具备的色氨酸、维生素B1、胡萝卜素等营养成分[1-2]。小米中还含有丰富的叶酸[3]与酚类[4],其药效显著且对人体有益,能够帮助调理肠胃,增强消化力,因此被誉为珍贵的营养补充食物[5]。印度谷螟,学名*Plodia interpunctella*(Hübner),属鳞翅目螟蛾科,是重要的仓储害虫之一[6]。该害虫广泛分布于世界各地[7]。印度谷螟在小米中繁殖能力强,由于幼虫喜食小米胚部,在小米内部及表面吐丝结网,造成小米结块变质,对小米破坏性极大[8]。目前防治印度谷螟的方法主要为使用化学药剂熏蒸[8],而生化药剂的大规模应用可引起环境污染、药剂残留、印度谷螟的抗药性增强[9]等一系列的问题。因此需要一种绿色环保、安全健康的方法有效控制印度谷螟的危害。

微波是一种可产生高频电磁场的电磁波,波长范围在1 mm~1 m,频率范围为300 MHz~300 GHz。微波能够对极性分子进行选择性加热,加热速率极快,并且可以减少食品加工后的营养

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流失[10]。陈培栋等[11]研究指出,微波处理可提高糙米的蒸煮品质;张晓红等[12]研究指出微波处理提高了大米的保鲜效果;微波技术还可用于防治粮食虫害,目前,已有微波用于小麦[13]、大米[14]等储粮害虫防治[15-19]方面的研究,利用该方法不仅绿色环保还安全健康。但微波防治虫害研究大多主要集中在微波直接辐照害虫的杀灭效果方面,对粮食作物内部不同深度处的虫害杀灭效果研究较少,大多没有考虑微波在粮食作物中能量衰减即穿透深度和穿透能力的问题,实际应用效果不太理想。

因此本研究使用频率为2450 MHz的微波和'晋谷21号'谷子品种,通过观察小米不同深度处印度谷螟卵的存活率和温度,比较辐照前后小米黏滞特性、色度和含水率的差异,了解微波杀灭效果和小米品质变化,探究微波在小米中的传播衰减规律。旨在找出微波杀灭小米中印度谷螟的致死作用的深度和照射强度,给出既能有效杀灭小米虫害又能提升小米品质的微波处理方法,为谷子储藏减少虫害和经济损失提供科学依据。

1　材料与方法

1.1　试验材料

名优谷子品种'晋谷21号';印度谷螟卵。

1.2　主要仪器设备

DGG-9140BD电热恒温鼓风干燥箱,上海森信实验仪器有限公司;KBF240恒温恒湿培养箱,德国BINDER公司;M165C/MC120HD体视显微镜,德国徕卡公司;Galanz G80F20CN2L-B8(SO)微波炉,广东格兰仕公司;UT320温度传感器,上海优利得电子有限公司;VS450色度仪,美国X-Rite公司;RVA快速黏度分析仪,澳大利亚Newport Scientific仪器公司;CP1502电子天平,奥豪斯上海有限公司。

1.3　试验方法

1.3.1 印度谷螟卵的获取

将有印度谷螟虫害的小米置于相对湿度70%、温度30 ℃的恒温恒湿培养箱,待出现大量印度谷螟成虫时将其放入透明塑料袋中,2~3 d后,当看到塑料袋中有大量卵时,将成虫移至另一塑料袋,原塑料袋内的卵取出备用。将卵置于体视显微镜下,用小毛笔轻轻挑取完整的印度谷螟卵,每30粒为1组,备用。

1.3.2 微波辐照剂量

将微波炉分别调整至160、320、480、640和800 W的功率档位,并分别采用5、10、15、20、25和30 s的处理时间。微波频率2450 MHz。

1.3.3 印度谷螟卵存活率

由于微波可以穿过玻璃、塑料且不消耗能量,取完整的30粒印度谷螟卵置于小塑料袋且将卵集中于一侧,选取可打开的半径3、5、8、10 cm的球形玻璃容器,通过测量使吊绳长等于半径后将卵吊置于球形玻璃容器中的圆心处,将玻璃容器装满小米后置于微波炉内进行微波辐照处理,微波直接辐照卵视为卵置于平铺小米表面(0 cm)处理,辐照处理后用体视显微镜观察卵的外部形态并将卵置于无纺布包好的20 g无污染的小米中,小米放置于相对湿度70%、温度30 ℃的恒温恒湿培养箱,20 d后观察小米的受损状态,计算卵孵化为幼虫的数量n,取n/30为卵存活率,每处理设3个平行,设置1组3个平行空白对照。

1.3.4 微波处理后小米温度变化

将温度计热电偶插入小米不同深度(0、3、5、8、10 cm),微波辐照处理后快速读取温度,每个处理组设3个重复。以深度为横坐标、温度为纵坐标绘制曲线,分析微波在小米介质中的穿透深度和穿透能力。

1.3.5 小米淀粉黏滞特性分析

将小米磨粉后,用澳大利亚Newport Scientific仪器公司生产的快速粘度分析仪RVA(Rapid Visco Analyzer,Model 3D)测定,用TCW(Thermal Cycle for Windows)配套软件分析[20]。每处理设3个平行,设置1组3个平行空白对照。

1.3.6 小米色度

采用SF600PLUS色度仪测定。每个处理样品和对照样品都重复测量3次。

1.3.7 小米含水率的变化

将小米平铺于微波炉内进行微波辐照后,用天平秤取20.000 g小米,置于65 ℃烘箱烘干,15 h内每隔0.5 h取出称重,直到连续取出2次后质量m不变,计算含水率为$\omega_1=(20.000-m)/20.000$,重复3次取平均值。设置1组3个平行空白对照,测其含水率为ω_0。$\omega_0-\omega_1$为含水率的变化。

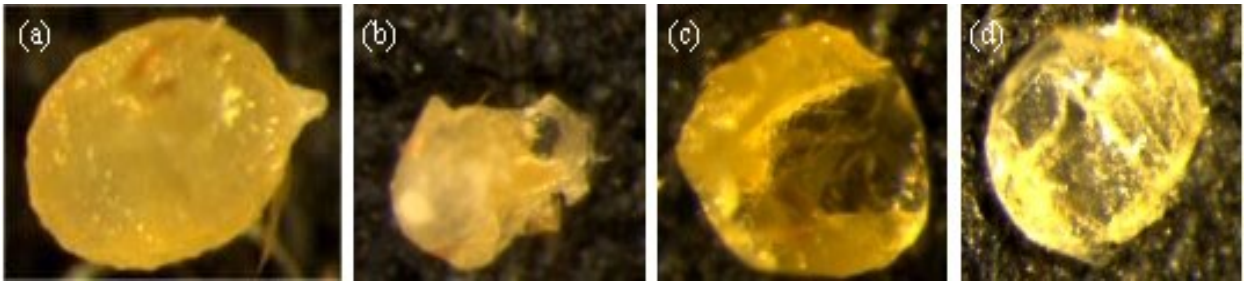
1.4 数据处理

采用Origin 8.5、SPSS 17.0统计软件进行绘图和数据统计分析。

2 结果分析

2.1 印度谷螟卵形态

正常的印度谷螟卵如图1a所示,长约0.4 mm左右,呈椭圆形,黄白色,一端为乳头状突起,卵面具有细的刻纹。图1b~图1d为经微波辐照后,变形、破裂的印度谷螟卵。图2a为30粒印度谷螟卵在20 g小米中自然存活20 d后,出现许多印度谷螟幼虫,产生大量粪便,小米受破坏严重、连缀成团,可见印度谷螟对小米的破坏力极强,控制印度谷螟的危害势在必行。

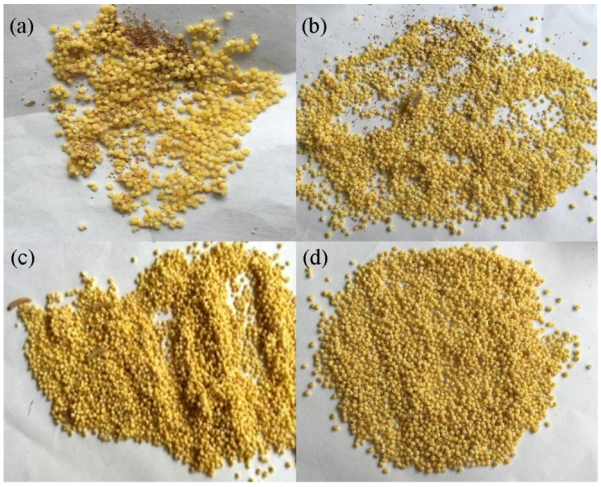


(a)正常卵;(b)800W20s微波辐照破裂的卵;(c)640W25s微波辐照破裂的卵;(d)480W30s微波辐照变形的卵

(a): The normal egg; (b): the ruptured egg under 800 W+20 s microwave treatment; (c): the ruptured egg under 640 W+25 s microwave treatment; (d): the deformed egg under 480 W+30 s microwave treatment

图1 印度谷螟卵形态

Fig.1 Morphology of *P. interpunctella* eggs



(a)未处理;(b)800W10s微波处理;(c)480W20s微波处理;(d)800W25s微波处理

(a) Untreated millets; (b) 800W10s treatment; (c) 480W20s treatment; (d) 800W25s treatment

图2 不同处理后的小米

Fig.2 The millet treated with different intensities of microwave irradiation with different duration

2.2 印度谷螟卵存活率

试验测得所用的印度谷螟卵的存活率为92%。图3为卵置于0 cm(平铺)小米中微波辐照后卵的存活率,可见,微波功率越大,辐照时间越长,卵的存活率就越低。功率为160 W的微波辐照处理后卵的存活率基本不变,对卵基本无危害;800W10s和480W20s微波处理卵的存活率分别为40%和27%,800W15s微波处理卵的存活率很低,800W20s、800W25s、800W30s、640W20s、640W25s、640W30s、480W25s、480W30s这8个处理卵的致死率为100%,可完全消灭印度谷螟卵。图2b、图2c为0 cm(平铺)800W10s和480W20s处理20 d后的小米,相比未经微波处理(图2a),小米破损程度明显减轻;图2d为800W25s处理后小米,未出现虫害,小米金黄发亮,没有受到损害。图1b~图1d为800W20s、640W25s、480W30s微波辐照后的印度谷螟卵,卵发生了破裂或变形,不能够发育为幼虫,阻止了印度谷螟的繁殖和对小米的破坏。结果表明,微波辐照方法可以有效防治小米储藏过程中产生的虫害,致死率可达到100%。

图4为微波辐照小米3、5、8、10 cm深处中卵的存活率,结果与0 cm(平铺)小米中卵的存活率差异明显。800W10s在5 cm处卵的存活率为80%,比0 cm处的存活率提高了1倍,480W20s在3 cm处卵的存活率为35%,比0 cm处的存活率提高34%。相同微波功率与辐照时间,深度越小卵的存活率越低。3 cm处只有800W20s、800W25s、800W30s、640W25s、640W30s、480W30s的6个处

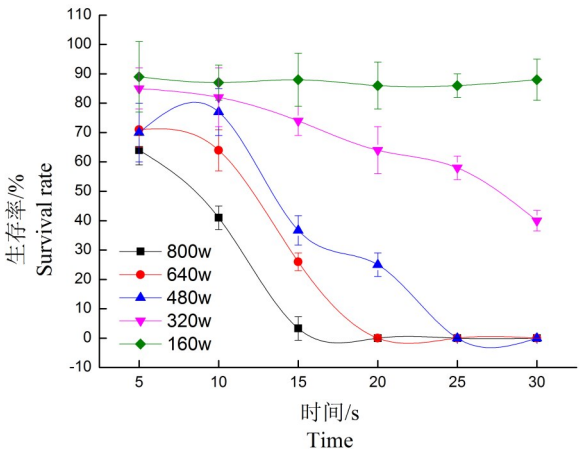


图3　0 cm深度(平铺)小米中卵的存活率

Fig.3　Survival rates of *P. interpunctella* eggs at 0 cm (the surface of millets)

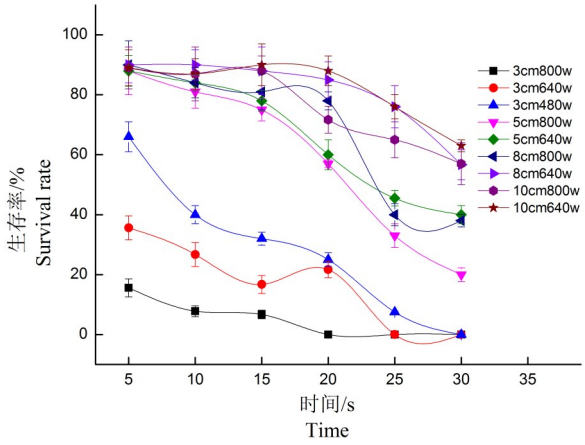


图4　不同深处卵的存活率

Fig.4　Survival rates of *P. interpunctella* eggs at different millet depths

理卵的致死率为100%,5 cm处800W30s处理卵的致死率最高为75%。8、10 cm深处卵的存活率都相对较高,灭卵效果不理想。

2.3　微波辐照对小米温度的影响

图5为微波辐照后小米不同深度处的温度曲线。图5a～图5c分别是0、3、5 cm处的温度,160 W各处理的温度波动很小,320 W辐照5、10、15、20 s后小米5 cm深度的温度无显著性差异,除此之外,微波功率越大、辐照时间越长,同一深度处小米温度越高。图5d为640W30s、800W20s、800W25s、800W30s处理在0、3、5、8、10 cm处的温度,相同微波功率与辐照时间下,小米表面温度最高,随着深度增加,小米内部温度下降。640W30s、800W20s、800W25s、800W30s处理10 cm处的温度没有显著性差异($P<0.05$)。将图5d中试验测得的小米深度和温度关系进行拟合,如图6所示,结果指出温度随深度以指数规律衰减,相关系数分别为0.99、0.96、0.97、0.98。说明深度是影响微波辐照小米温度的重要因素之一。

2.4　微波辐照对小米黏滞特性的影响

利用快速黏度分析仪可快速分析作物的品质性状。将微波辐照平铺的小米放置20 d,用快速黏度分析仪测量黏滞特性。在测定过程中,产生峰值黏度、热浆黏度、最终黏度、衰减值、回生值、糊化温度等6个特征指标,表1为测定结果。

640W30s和800W20s微波处理的峰值粘度上

表1　不同微波处理后小米的RVA谱特征值

Table 1　Effects of different microwave irradiation on millet RVA profiles

功率/W Power	时间/s Time	峰值黏度/cp Peak viscosity	热浆黏度/cp Trough viscosity	最终黏度/cp Final viscosity	衰减值/cp Breakdown	回生值/cp cpSetback	糊化温度/℃ Pasting temperature
480	25	1745±5b	789±21a	2018±34c	919±27b	1251±26a	76.53±0.20b
480	30	1740±16b	769±10a	2021±10c	930±15b	1269±10a	75.55±0.36d
640	20	1730±17b	779±15a	2103±25b	927±25b	1239±12a	76.22±0.31c
640	25	1719±22b	767±17a	2108±23b	928±22b	1321±22a	76.12±0.41c
640	30	1774±9a	783±6a	2097±6b	990±7a	1316±14a	75.02±0.21e
800	20	1768±18a	785±10a	2002±32c	938±10b	1254±26a	75.07±0.22e
800	25	1498±9f	747±13d	2026±14c	671±10h	1332±4a	76.58±0.61b
800	30	1419±24g	773±3b	2246±7a	745±5fg	1236±11a	77.42±0.62a
未处理		1722±7b	797±12a	2220±54a	924±7bc	1242±48a	76.65±1.11b

注:同列不同小写英文字母表示差异显著($P<0.05$)。未处理组不进行微波辐照,其余操作相同

Note:Different small letters in the same column indicated significant difference at $P<0.05$. Control groups were treated in the same manner without microwave irradiation

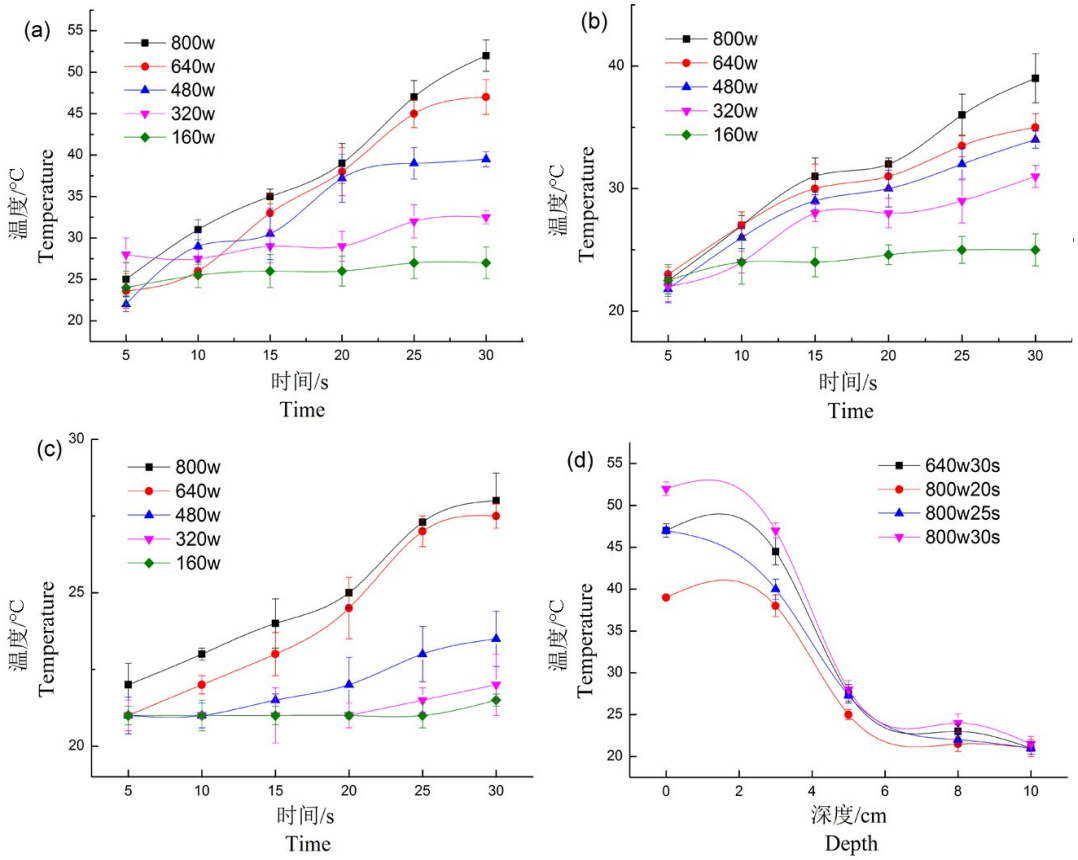


图5 小米不同深度处的温度

Fig. 5 Effects of microwave irradiation time on millet temperature

升,800W25s和800W30s处理峰值粘度降低,其它处理无显著差异($P<0.05$);800W20s和800W25s处理热浆黏度降低,其它处理无显著性差异;800W30s处理最终黏度没有发生显著变化,其它处理显著降低;640W30s处理衰减值升高,800W25s和800W30s处理衰减值下降,其它处理无显著差异;各处理回生值没有显著差异;480W25s和800W25s处理的糊化温度没有显著性变化,800W30s处理的糊化温度升高,其它处理糊化温度降低。

2.5 微波辐照对小米色度的影响

对平铺的小米进行微波处理,20 d后通过色差仪对小米样品进行米色测定(表2)。从表中数据可以看出,除800W30s处理样品的a*、b*和h*值与未处理小米有显著差异外,其它处理无显著差异。表明800W30s高强度微波处理影响小米色度。

2.6 微波辐照对小米含水率的影响

用烘干法测得‘晋谷21号’小米的含水率8.762%。微波辐照平铺小米后测定其含水率,与未处理小米的含水率进行比较,绘制含水率下降幅度的变化曲线。如图7所示,微波辐照处理后小米的含水率都显著降低($P<0.05$),640W30s处理后含水率降低0.9%,800W25s处理后含水率降低0.85%,800W30s含水率下降最多为1.24%。微波功率越大,辐照时间越长,水分减少的越多。

3 讨论

3.1 深度对微波辐照灭卵效果的影响

采用800W15s、640W20s、480W25s微波处理能实现小米0 cm(平铺)处印度谷螟卵致死,3 cm深度处微波强度需增加到800W20s、640W25s、480W30s才能达到卵致死,5 cm深处采用最高强度800W30s微波处理卵致死率最高仅为75%,8、10 cm深处微波辐照后卵的存活率仍相对较高,灭卵效果不佳。小米深度是影响微波辐照灭卵效果的重要因素,深度越小,效果越好。这与戴秋慧

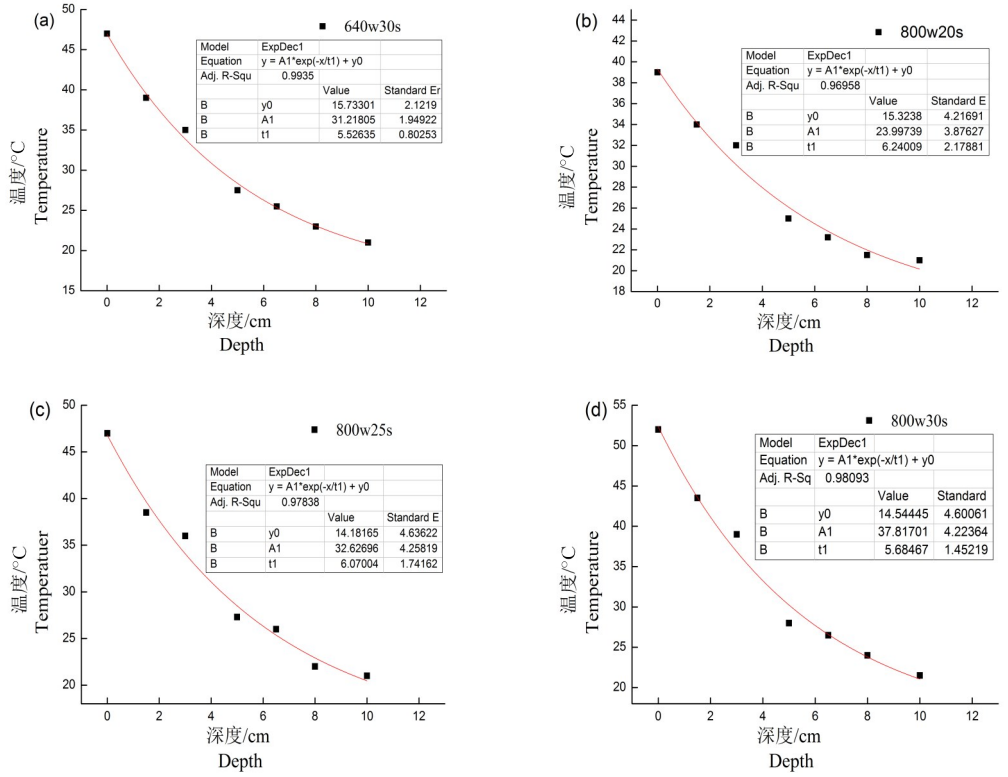


图6　温度随深度以指数规律衰减

Fig.6　Fitting relationship between millet depth and millet temperature

等[21]研究结果相一致。频率2450 MHz的微波在介质中传播时,使介质分子每秒震动2.45×10^{10}次,导致介质温度升高[22],表明微波在小米中传播时有明显的能量损耗。试验结果表明2450 MHz微波辐照小米灭卵时小米厚度不宜超过3 cm。微波不易处理大块或厚度大的物料,这也是目前微波灭卵存在的主要问题和不易推广使用的重要原因。对于小米的微波灭卵,可采用平铺小米减少小米的厚度的方法达到较好的灭卵效果。

3.2　微波辐照对小米品质的影响

将小米磨粉后,用快速粘度分析仪测定淀粉粘滞特性,由于模拟了米饭的蒸煮过程,其特征值与小米蒸煮食味品质密切相关[22]。因此,小米RVA特征值可作为评价小米蒸煮食味品质优劣的重要指标[24]。糊化特性反映了谷物淀粉的质构和热特性[20],峰值粘度是烹调后立即达到的最大粘度,它是淀粉颗粒膨胀与破裂的平衡点[25]。峰值粘度影响淀粉产品的质量[26]。一些研究表明,峰值粘度反映了α-淀粉酶活性[27-28]。一般而言,粘度越高,谷物的口感越好[29]。就此来说,640W30s和800W20s微波辐照后小米的峰值粘度升高,提升了小米的食味品质;热浆黏度和最终黏度越低,谷子中直链淀粉含量越少,质量更好[29]。结果表明,800W20s和800W25s微波辐照后小米的热浆黏度和最终黏度降低,提升了小米质量。其它处理都没有使热浆黏度和最终黏度升高,不影响小米质量;衰减值是凝胶溶胀后增稠的指标,数值越高,味道越好[29]。640W30s微波辐照后小米的衰减值升高,提升了小米的食味品质;糊化温度是烹饪食物所需的最低温度[25],糊化温度反映了小米的烹饪质量,糊化温度高的小米在烹饪时需要更多的水和更长的时间,食用一般以中、低糊化温度较好[30]。除480W25s、800W25s和800W30s外,其它微波辐照后小米的糊化温度都降低了,提升了小米的食味品质。经过比较分析,除800W25s和800W30s外,其它微波辐照不会对小米品质产生影响,640W30s微波辐照提升了小米的食用品质。任秀娟等[31]研究指出,适当的微波处理可提高全麦粉适用品质,但过度微波处理会导致全麦粉品质劣变。王泽伦等[10]指出,微波处理可提高糙米

表2 微波辐照对小米色度的影响

Table 2 Effects of different microwave irradiation levels on millet color

功率/W Power	时间/s Time	亮度 L*	红绿度 a*	黄蓝度 b*	彩色程度 c*	灰度 h*
160	5	66.31±0.80a	9.09±0.10a	48.94±0.62a	49.78±0.62a	79.48±0.09b
	10	67.32±0.92a	9.27±0.06a	49.40±0.73a	50.26±0.72a	79.37±0.15b
	15	67.05±0.71a	9.15±0.12a	49.21±0.35a	50.06±0.36a	79.47±0.07b
	20	67.05±0.59a	9.32±0.18a	49.08±0.73a	49.96±0.75a	79.25±0.05b
	25	66.39±1.36a	9.18±0.26a	48.43±1.48a	49.30±1.50a	79.26±0.10b
	30	66.20±0.87a	9.27±0.03a	48.90±0.85a	49.77±0.83a	79.27±0.20b
320	5	66.08±0.28a	9.14±0.06a	47.96±0.09a	48.82±0.10a	79.20±0.06b
	10	66.60±0.33a	9.12±0.18a	48.82±0.03a	49.67±0.05a	79.42±0.20b
	15	66.48±0.59a	9.13±0.17a	47.87±0.20a	48.73±0.17a	79.20±0.23b
	20	66.51±0.54a	9.21±0.20a	49.18±0.88a	50.03±0.90a	79.39±0.10b
	25	65.62±1.24a	9.11±0.14a	48.25±0.85a	49.10±0.86a	79.30±0.09b
	30	66.35±0.81a	8.97±0.09a	48.32±0.15a	49.14±0.13a	79.48±0.13b
480	5	67.81±0.84a	9.18±0.19a	48.98±0.47a	49.77±0.49a	79.38±0.12b
	10	65.85±0.94a	9.16±0.23a	48.80±0.66a	49.66±0.69a	79.37±0.15b
	15	66.22±0.95a	8.96±0.08a	48.47±0.96a	49.29±0.95a	79.53±0.16b
	20	65.89±0.38a	8.95±0.05a	48.24±0.27a	49.07±0.27a	79.49±0.06b
	25	67.34±0.54a	9.00±0.21a	48.90±0.31a	49.73±0.31a	79.57±0.25b
	30	67.39±0.40a	8.92±0.05a	48.94±0.33a	49.74±0.32a	79.67±0.09b
640	5	67.11±0.94a	9.10±0.15a	49.14±1.34a	49.98±1.34a	79.50±0.12b
	10	67.38±0.55a	9.29±0.18a	48.99±0.90a	49.86±0.92a	79.26±0.07b
	15	67.01±0.55a	9.07±0.29a	49.24±0.35a	50.07±0.30a	79.56±0.39b
	20	66.41±0.88a	9.09±0.23a	48.50±0.90a	49.34±0.93a	79.38±0.09b
	25	66.21±0.72a	8.91±0.08a	48.67±0.59a	49.48±0.58a	79.62±0.11b
	30	67.45±0.42a	8.92±0.13a	48.98±0.35a	49.78±0.36a	79.72±0.07b
800	5	66.99±0.72a	9.18±0.15a	49.39±0.54a	50.23±0.53a	79.47±0.18b
	10	65.68±0.36a	9.03±0.08a	48.08±0.62a	48.92±0.61a	79.36±0.15b
	15	67.23±0.86a	9.23±0.13a	49.09±0.43a	49.95±0.44a	79.36±0.10b
	20	67.70±0.73a	9.02±0.38a	49.96±0.72a	50.77±0.78a	79.77±0.28b
	25	66.13±0.41a	9.04±0.16a	48.46±0.33a	49.30±0.35a	79.43±0.12b
	30	66.51±0.84a	8.61±0.24bB	48.03±0.92b	48.79±0.95a	79.83±0.09a
未处理		67.36±0.05a	9.25±0.05aA	49.60±0.30a	50.45±0.29a	79.43±0.11b

注:同列不同大、小写英文字母分别表示差异极显著($P<0.01$)和差异显著($P<0.05$)。未处理组不进行微波辐照,其余操作相同

Note: Values in the same column with different small letters indicated significant difference at $P<0.05$. Values in the same column with different capital letters indicated significant differences at $P<0.01$. Control groups were treated in the same manner without microwave irradiation

蒸煮品质。目前,微波影响食品风味变化是国内外研究热点[32],微波技术已应用于淀粉改性[33]和改善食品品质方面。

800W30s高强度微波处理影响小米色度,表明微波处理小米时强度要适当。小米的色度是评估其质量的关键视觉指标[34],很大程度上影响加工品质[35]。与其它品质指标相比,以色度评判是最简单、快捷的评估方法。目前已有大量关于颜色变化的动力学研究报道[36]。研究指出类胡萝卜素组合对谷子颜色有重要影响[34]。汪小娉等[37]指出微波强度对南瓜中类胡萝卜素的影响十分明显,随着微波强度的增加,总类胡萝卜素含量显著降低。也有研究指出低温环境可以有效类防止胡萝卜素氧化降解[38]。

水分含量是影响谷类质量的关键指标[10],水分含量过高导致小米储存时易发霉变质,小米的含水率是重要的储藏安全指标[39]。微波辐照处理后小米的含水率不同程度地降低,说明微波处理

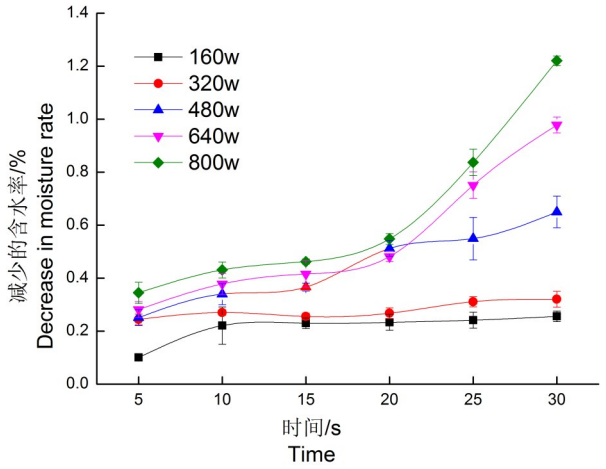


图7　微波辐照后小米含水率的变化

Fig.7　Effects of microwave irradiation duration on the change of moisture content in millets

为储藏小米创造了更好的条件。水分子有很强的极性,是吸收微波的最好介质[40]。小米中的水分子在微波高频电场下发生极化,随高频交变电场方向的交互变化而转动,并产生剧烈的碰撞和摩擦,一部分微波能转化为分子运动能以热量的形式表现出来,使水的温度升高而脱离物料[41]。夏吉庆等[30]研究指出,高含水率的贮藏会加速大米的水解而导致脂肪酸的价值降低,使得稻米品质下降。张敏等[42]研究指出大米水分含量过高,在储存过程中会导致大米霉变、虫蛀、陈化等。适当的水分减少可以防止小米在储藏过程中发生霉变而变质[43]。目前,微波技术已经应用于干燥领域,王童等[44]为了减少花生收获后因未及时干燥而造成的霉变损失,采用微波干燥技术对花生进行干燥。Shen等[45]研究发现,微波干燥是糙米干燥的一种可行方法,并且具有能源效率高、成本低、易控制等明显优势。

通过试验结果结合上述分析,640W30s微波辐照提升了小米品质,800W25s和800W30s高强度微波辐照因影响小米品质而不宜采用。

4　结论

微波在小米中传播时能量随深度衰减,当同一强度的微波到达小米的不同深度处时,微波的强度也发生变化,导致对不同深度处的印度谷螟卵的杀灭效果不同,深度越小,灭卵效果越好。同时高强度微波影响小米的品质。综合上述结果,采用640W30s微波辐照3 cm厚度内小米,既能有效灭卵又能提升小米的品质。微波辐照具有时间短、无污染和无抗性产生等优点,是一种环保的虫害控制方法。该方法既实现了高效的虫害治理,又不影响作物品质,是一种值得推广的防虫技术。

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Effects of microwave irradiation on *Plodia interpunctella* eggs in millet and its impact on millet quality

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Abstract: [Objective] *Plodia interpunctella* has a strong reproductive ability in millet and causes significant damage. The commonly used chemical fumigation control methods are prone to environmental pollution, pesticide residues, and increased resis-

tance of *Plodia interpunctella* moths. Microwave technology can be used for grain pest control and is environmentally friendly. This study aimed to investigate the influence of microwave irradiation on the elimination of *P. interpunctella* eggs in millets and its impact on millet quality. [Methods]Millet was irradiated with microwaves at power levels of 160 W, 320 W, 480 W, 640 W, 800 W for 5, 10, 15, 20, 25, and 30 seconds. The survival rate of *Plodia interpunctella* eggs at depths of 0, 3, 5, 8, and 10 cm and the temperature of millet were measured to observe the egg elimination effect and microwave transmission pattern at different depths of millet. The viscosity, color, and moisture content of millet were also measured after microwave irradiation to assess the impact of microwave irradiation on the quality of millet. [Results]With the same power and time of microwave irradiation, the shallower the depth, the lower the survival rate of eggs and the better the egg elimination effect. Low-intensity microwaves at 160W30s and 320W15s could not eliminate eggs as their external morphology remained unchanged. Microwaves at 800W15s, 640W20s, and 480W25s effectively eliminated eggs at 0 cm (surface) depth. Microwaves at 800W20s, 640W25s, and 480W30s effectively destroyed eggs at 3 cm depth. After high-intensity microwave irradiation at 800W+30s, the survival rate of eggs at 5cm depth was 25%, and the survival rate at the depth of 8cm and 10cm remained relatively high, indicating poor egg eliminate effect. The internal temperature of millet decreases exponentially with depth under the same power and time of microwave irradiation. Microwave irradiation at 640W30s increased the peak viscosity and breakdown value of millet, while irradiation at 480W25s, 800W25s, and 800W30s increased the gelatinization temperature of millet. Except for the high intensity microwave treatment of 800W30s microwave irradiation did not affect the color of millet; Microwave irradiation reduced the moisture content of millet, which created better conditions for millet storage. Microwave irradiation at 640W30s improved the eating quality of millet, while high-intensity irradiation at 800W25s and 800W30s reduced the quality of millet. [Conclusion] Millet depth is an important factor affecting the egg elimination effect of microwave irradiation, and the millet depth should not exceed 3cm for effective egg elimination. Microwave irradiation at 640W30s for millet within 3 cm depth can effectively destroy eggs and improve millet quality. This study provided scientific basis for using microwave technology to control millet storage pests and reduce economic losses.

Keywords: Microwave, Eggs of *P. interpunctella*, Depth, Effect of egg elimination, Millet Quality

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