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叶面喷施硒肥对小麦籽粒及面粉硒含量的影响

张平平* 马鸿翔 姚金保 张 鹏
(江苏省农业科学院粮食作物研究所/江苏省现代作物生产协同创新中心,江苏 南京 210014)

摘 要:为了探明叶面喷施硒肥对小麦籽粒及制粉各粉路硒含量的影响,本研究选用4个小麦品种,在拔节和抽穗期分2次喷施0.017%亚硒酸钠叶面肥,并对成熟期籽粒进行制粉,分析各粉路的总硒、无机硒和有机硒含量。结果表明,叶面喷硒对小麦籽粒和面粉的总硒、有机硒和无机硒含量的影响存在品种间差异。喷施硒肥后,4个小麦品种籽粒的总硒含量提高了26.4~35.8倍,但小麦籽粒产量无显著变化。皮磨粉、心磨粉、统粉、小麸和大麸5种粉路中,小麸的总硒含量最高,其次为大麸,皮磨粉、心磨粉和统粉的总硒含量较低。与硬质小麦相比,软质小麦出粉率低,面粉的总硒量损失较多。经制粉,对照和喷硒样本的总硒积累量分别损失52.97%~69.28%和36.73%~44.51%。对照样本中,各粉路的有机硒含量略高于无机硒含量;而喷硒处理样品中,除宁麦20的小麸外,各粉路的有机硒含量均略低于无机硒含量。本研究揭示了制粉粉路硒分布规律,这对于富硒小麦的加工利用具有重要的指导作用。

关键词:叶面硒肥; 籽粒; 面粉; 硒含量
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硒(selenium,Se)是人体和动物生长发育所必需的微量元素[1-3],通常在饮食中含量极低,难以满足健康生理所需,很多国家和地区都面临缺硒引发的问题[4-5]。小麦作为人类最主要的粮食作物之一,其含有的硒在人体中表现出较高的吸收利用率,因此提高小麦硒含量有助于改善人们对硒的摄入量[4,6-8]。小麦基因型间硒含量存在差异,具有遗传改良的潜力[9-10],但小麦生长环境,尤其是土壤硒含量对小麦硒含量的影响更大[4,11-14]。研究表明,小麦对硒具有较高的吸收积累和生物转化能力,通过农艺措施能够显著提高小麦籽粒的硒含量[13,15-17]。硒在小麦籽粒中主要以无机硒(如硒酸和亚硒酸)和有机硒(多与氨基酸螯合形成硒代氨基酸,如硒代蛋氨酸[18])的形式存在,有机硒较无机硒有更高的生物利用率[8]。Galinha等[5]和Hart等[15]进一步研究发现,施用硒肥后小麦籽粒中的有机硒含量超过50%,且主要以硒代蛋氨酸形式存在。制粉对面粉硒含量的影响也较大[10, 19-21],各部分硒含量整体表现为胚>麸皮>胚乳[5,15, 22-24]。硒肥在改变小麦籽粒硒含量的同时,也会对小麦的生长发育产生影响。研究表明,低剂量的硒肥能够在非生物胁迫下维持小麦的正常生理代谢,提高抗氧化能力,进而稳定或增加小麦产量[3,25];而高剂量的硒肥可能会抑制生长或拮抗其他营养元素的吸收[6]。因此,进一步探讨农艺措施对小麦总硒、有机硒和无机硒含量的影响,研究制粉对硒分布的影响,对富硒小麦的生产及加工具有重要的指导意义。

1 材料与方法

1.1 试验区概况

本试验于2016-2017年在江苏省农业科学院六合基地进行,该基地属于典型的稻麦轮作区域,前茬水稻,播前20 cm土层肥力水平为水解氮93.7 mg·kg^{-1}、速效磷40.5 mg·kg^{-1}、速效钾85.7 mg·kg^{-1}、有机质含量14.4 g·kg^{-1}、总硒含量0.164 mg·kg^{-1}。

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作者简介:张平平,男,研究员,主要从事小麦遗传育种研究。E-mail:pp_zh@126.com
***通讯作者**:同第一作者。

1.2 试验设计

采用两因素随机区组设计,以品种为主区,选用4个红皮冬小麦品种,分别为宁麦13、宁麦17、宁麦20和生选6号;以喷施叶面硒肥为副区,每个品种设对照(CK,喷施清水)和喷施叶面硒肥2种处理。喷施方法:于小麦拔节期(2017年3月16日)和抽穗期(2017年3月30日)2次等量喷施0.017%亚硒酸钠水溶液,喷施量为750 kg·hm^{-2}。3次重复,小区面积13.34 m^2,5 m行长,每小区10行。各品种的其他栽培管理条件一致,基本苗为2.25×10^6 hm^{-2},N、P_2O_5和K_2O的施用量分别为225、112和112 kg·hm^{-2},其中N肥基追比为5(基肥):2(分蘖肥):3(拔节肥)。成熟期按小区收获种子并过筛清理杂质和破损粒。

1.3 硒含量测定

每个小区取3.5 kg籽粒样本,清洁3次后摊平晒干备用。每个小区的籽粒样本取200 g,经FOSS Cyclotec 1093实验磨(FOSS,瑞典)磨粉并充分混匀、过筛,获得全麦粉样本。采用Perten SKCS 4100单籽粒硬度仪(Perten,美国)测定籽粒硬度,根据硬度将样本分为两类:硬质类型为宁麦13和宁麦17;软质类型为宁麦20和生选6号。硬质、软质样本分别于室温润麦18 h至含水量为16.0%和14.0%,参照AACC 26-21A的方法[26],使用布勒MLU 202实验磨(Bühler,德国)制粉。每个小区的籽粒样本经制粉后分离为皮磨粉、心磨粉、小麸和大麸四部分。皮磨粉和心磨粉分别充分混匀后得皮磨粉样本和心磨粉样本。分别取50%的皮磨粉样本和50%心磨粉样本,混合均匀后得统粉样本。小麸和大麸分别充分混匀后,经四分法各取200 g,再经FOSS Cyclotec 1093实验磨分别磨制和混匀后得小麸和大麸样本。取全麦粉、小麸、大麸、皮磨、心磨和统粉样本各50 g,70℃烘干至恒重,置于干燥器中备用。

参照GB 5009.93-2017[27]的方法:准确称取1.000 g粉样,经HNO_3:$HClO_4$(9:1)消化后定容至50 mL,采用氢化物原子荧光光谱法测定总硒含量。参照DB3301/T 117-2007[28]的方法:称取2.5 g粉样,经20 mL 6 mol·L^{-1}盐酸溶解,70℃恒温水浴振荡浸提2 h并定容至25 mL,过滤。取12.5 mL滤液沸水浴20 min,冷却后依次加入2.5 mL铁氰化钾溶液和3滴正辛醇,加水定容至25 mL,采用氢化物原子荧光光谱法测定无机硒含量。有机硒含量=总硒含量-无机硒含量。

1.4 数据分析

使用SAS 1997软件对所得数据进行方差分析、基本统计量分析和显著性检验。

2 结果与分析

2.1 叶面喷施硒肥对小麦籽粒硒含量的影响

由表1可知,4个品种小麦中对照组的总硒含量都较低,为0.058 0~0.075 0 mg·kg^{-1}。叶面喷硒处理显著提高了籽粒的总硒含量,达1.810 4~2.515 5 mg·kg^{-1},是对照组的26.4~35.8倍。对照组中有机硒的比例高于无机硒,占比为53.3%~68.1%;而喷硒处理中有机硒的比例较低,占比为40.6%~46.2%。在对照和硒肥处理样本中宁麦20的有机硒占比均为最高。

表1 叶面喷施硒肥处理对小麦籽粒硒含量的影响

Table 1 Effect of Se foliar spray on the kernel Se content of common wheat /(mg·kg^{-1})

品种 Varieties	处理 Treatments	有机硒含量 Organic Se content	无机硒含量 Inorganic Se content	总硒含量 Total Se content
宁麦13 Ningmai 13	对照	0.0365±0.0007b	0.032 0±0.002 8b	0.068 5±0.002 1b
	喷硒	0.7604±0.0503a	1.050 0±0.011 3a	1.810 4±0.061 6a
宁麦17 Ningmai 17	对照	0.0410±0.001 4b	0.028 5±0.002 1b	0.069 5±0.003 6b
	喷硒	0.8165±0.007 8a	1.103 5±0.003 5a	1.920 0±0.004 2a
宁麦20 Ningmai 20	对照	0.0395±0.003 5b	0.018 5±0.000 7b	0.058 0±0.004 2b
	喷硒	0.9595±0.003 4a	1.119 0±0.011 3a	2.078 5±0.024 7a
生选6号 Shengxuan 6	对照	0.046 0±0.001 4b	0.029 0±0.002 8b	0.075 0±0.004 2b
	喷硒	1.021 5±0.009 2a	1.494 0±0.053 7a	2.515 5±0.062 9a

注:不同小写字母表示同一品种对照和喷硒处理间差异显著(P<0.05)。

Note: Different lowercase letters indicate significant difference at 0.05 level between the control and the Se foliar spray kernel sample for each tested variety.

2.2 叶面喷硒对粉路产率及统粉总硒损失率的影响

小麦各粉路产率与相应粉路的硒含量和硒损失率有关。由表2可知,各处理不同品种间小麦粉路产率差异较大,宁麦13和宁麦17的统粉产率高于宁麦20和生选6号,但皮磨粉、小麸和大麸产率相反。此外,喷硒处理显著降低了皮磨粉产率;除宁麦20外,喷硒处理提高了心磨粉产率,但仅在生选6号中差异显著;除生选6号外,喷硒处理增加了小麸产率;喷硒处理还显著降低了生选6号的大麸产率,但对其他3个品种的影响不显著。

喷硒处理显著降低了总硒积累量在统粉中的损失率,4个小麦品种对照组中统粉总硒损失率为52.97%~69.28%,而喷硒处理后统粉总硒损失率为36.73%~44.51%。宁麦13和宁麦17的总硒损失率无论在对照样本还是在喷硒处理样本中均低于宁麦20和生选6号。

表2 磨粉各粉路产率及统粉总硒损失率

Table 2 Percentage of milling fractions and total Se loss in straight flour /%

品种 Varieties	处理 Treatments	皮磨粉产率 Break flour yield	心磨粉产率 Reduction flour yield	小麸产率 Shorts yield	大麸产率 Bran yield	统粉产率 Straight flour yield	统粉总硒损失率 Total Se loss in straight flour
宁麦13 Ningmai 13	对照	16.95±0.03c	55.53±0.36ab	8.86±0.28c	18.66±0.68cd	72.48±0.40a	53.80±1.08c
	喷硒	15.04±0.19d	56.95±0.08a	10.05±0.53bc	17.96±0.42d	72.48±0.40ab	36.73±1.17f
宁麦17 Ningmai 17	对照	18.34±0.91b	53.13±0.73b	9.92±0.46bc	18.61±0.64cd	71.47±0.18ab	52.97±0.71c
	喷硒	16.68±0.85c	53.26±2.02b	10.51±0.59b	19.55±0.58c	69.94±1.17bc	38.58±2.29ef
宁麦20 Ningmai 20	对照	20.13±0.01a	45.52±0.49d	11.20±0.16ab	23.15±0.33a	65.65±0.48de	66.40±0.53b
	喷硒	18.90±0.54b	45.47±0.01d	12.58±0.75a	23.05±0.20a	64.37±0.55e	44.51±0.09d
生选6号 Shengxuan 6	对照	21.06±0.09a	43.42±2.03d	12.04±1.02a	23.49±1.11a	64.48±2.12e	69.28±0.00a
	喷硒	18.82±0.26b	48.95±1.08c	10.65±0.37b	21.59±0.45b	67.77±0.83cd	40.22±1.09e

注:同列不同字母表示样本间差异显著($P<0.05$)。

Note: Different lowercase letters in the same column indicate significant difference among all samples at 0.05 level.

2.3 叶面喷施硒肥对小麦粉路硒含量的影响

由图1可知,从小麸和大麸2个非面粉粉路看,总硒、有机硒和无机硒含量在对照和喷硒处理中整体表现为小麸>大麸,其中,与对照相比,宁麦20喷硒处理后的无机硒含量、生选6号喷硒后的总硒含量差异不显著,且小麸中各类硒含量均显著高于其他粉路。从皮磨粉、心磨粉和统粉3种粉样看,总硒、有机硒和无机硒含量在对照组中均表现为皮磨粉>统粉>心磨粉。宁麦13喷硒处理后皮磨粉的总硒、有机硒和无机硒含量均显著高于心磨粉和统粉。宁麦17喷硒处理后皮磨粉的总硒、有机硒和无机硒含量则低于心磨粉和统粉,其中有机硒、总硒含量显著低于心磨粉和统粉。宁麦20和生选6号喷硒处理后总硒、有机硒和无机硒含量在皮磨粉、心磨粉和统粉3种粉样中均无显著差异。

2.4 叶面喷施硒肥对小麦籽粒产量的影响

由表3可知,喷硒处理提高了4个小麦品种的千粒重,其中宁麦13和宁麦17的千粒重显著高于对照。喷硒处理提高了4个小麦品种的产量,但均未达显著水平。此外,喷硒处理对4个小麦品种的穗数和穗粒数均无显著影响。

3 讨论

已有研究表明,籽粒硒含量与土壤硒含量和籽粒产量有关。在一定产量水平下,籽粒硒含量主要依赖于土壤硒含量[11-14,17],如本研究在田间试验土壤硒含量较低的条件下,对照(喷施清水)组各小麦品种的籽粒硒含量均较低。而在一定的土壤硒水平下,籽粒硒含量则随着籽粒产量的变化而变化,如Fan等[29]在Broadbalk小麦试验站160年的定位研究表明,不施肥条件下籽粒硒含量最高。增施硒肥可作为提高小麦硒含量的重要途径,且籽粒和面粉的硒含量与硒肥施用量呈线性相关[15-17,30-31],如本研究叶面喷硒使得各品种籽粒总硒含量提高了26.4~35.8倍。不同小麦品种对总硒的积累能力不同,Souza等[9]在研究20个巴西小麦品种时发现,施用硒肥后籽粒硒含量差异可达1.5倍。本研究也得出类似的结果,生选6号具有最强的硒积累能力,同时有机硒含量也表现最高。本研究在前人分层剥离研究籽粒硒分布的基础上[15,19],进一步通过工业制粉方法探明了总硒、无机硒和有机硒

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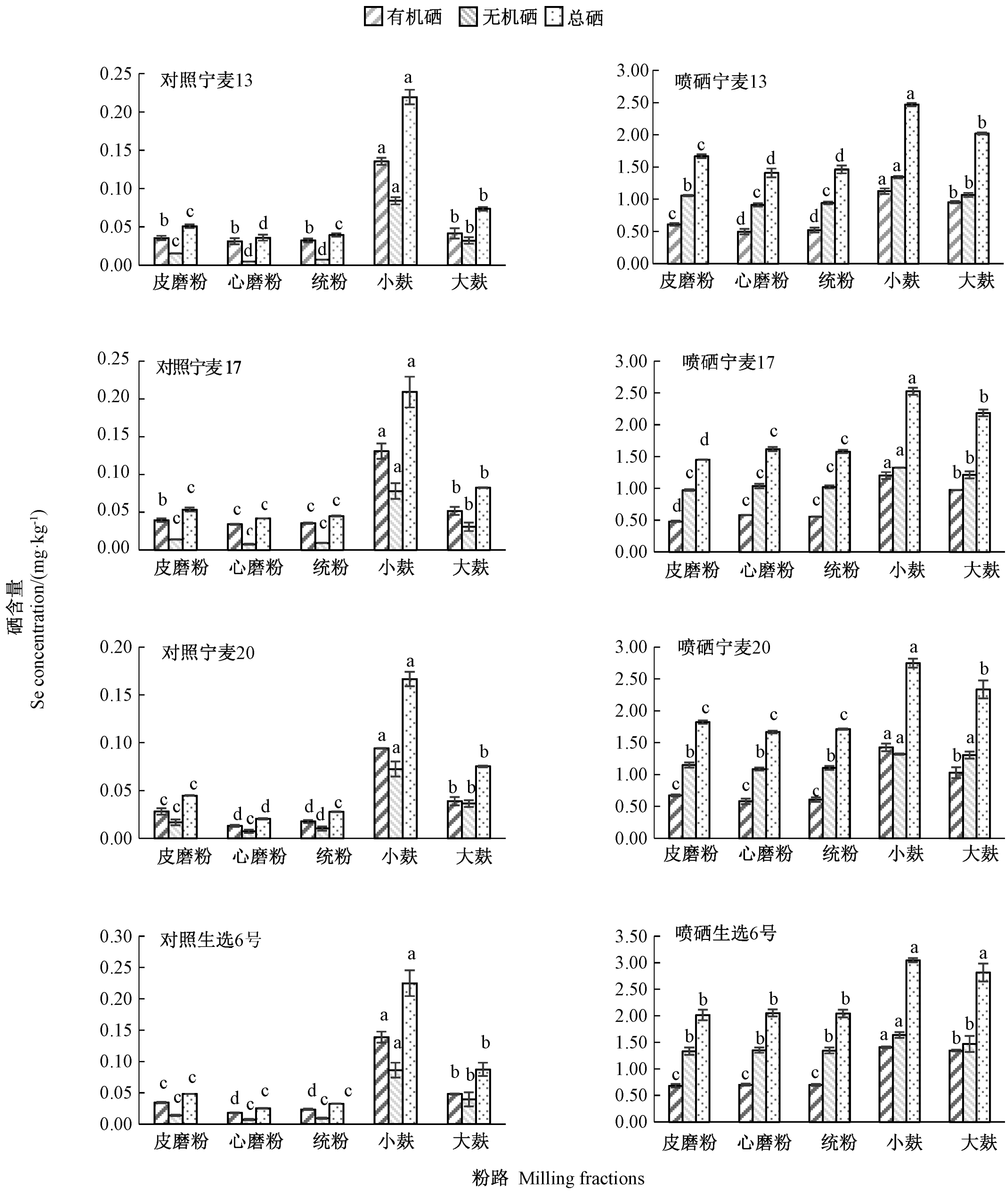

注:不同字母表示粉路间有机硒、无机硒和总硒含量之间差异显著($P<0.05$)。

Note: Different lowercase letters indicate significant difference at 0.05 level among milling fractions in organic Se, inorganic Se and total Se content.

图 1　各粉路有机硒和无机硒含量的比较

Fig.1　Comparison of organic and inorganic Se content in milling fractions

对照样本和喷硒处理样本中的分布,并探讨了品种差异性,发现包括籽粒硬度在内的基因型差异是硒积累能力、籽粒中硒分布的重要因素,应在富硒小麦种植和面粉深加工中加以考虑。就喷施硒肥的方法,本研究未采用前人建议的方法[5],即在拔节期和灌浆期 2 次喷施,而是选择在拔节期和抽穗期喷施,不仅大幅提高了籽粒的总硒含量,而且避免了灌浆期喷硒可能引起的籽粒无机硒污染[32],表明本试验方法是提高小麦硒含量安全有效的方法。

喷施硒肥不仅可以改变籽粒的硒含量,还可提高小麦的非生物逆境抗性。Nawaz 等[3]研究表明,干旱胁迫下叶面喷硒通过调节小麦的生理和生物化学代谢途径,显著提高了小麦的生物量及经济产量。Iqbal 等[25]发现喷硒还可显著改善小麦的热胁迫抗性。但在正常灌水和田间管理条件下,喷硒对产量性状无显著影响[3,17,30]。本研究试验地点位于长江中下游地区,试验点降雨充沛、气温适宜,因此喷硒并未显著影响各品种的籽粒产量,与前期研究结论相似[33]。

表 3 叶面喷施硒肥对产量性状的影响

Table 3 Effect of Se foliar fertilizer on the kernel yield and yield components

品种 Varieties	处理 Treatments	千粒重 Thousand-kernel weight/g	穗数 Spike number /($\times 10^6$ hm^{-2})	穗粒数 Kernel number per spike	产量 Yield /($\times 10^3$ kg·hm^{-2})
宁麦 13 Ningmai 13	对照	39.9±0.8b	4.74±0.21a	41.0±0.2a	7.07±0.28a
	喷硒	41.7±0.4a	4.70±0.32a	41.5±0.5a	7.46±0.29a
宁麦 17 Ningmai 17	对照	49.4±0.3b	3.96±0.23a	40.2±1.0a	6.95±0.53a
	喷硒	51.6±0.5a	3.93±0.32a	39.9±1.0a	7.31±0.46a
宁麦 20 Ningmai 20	对照	38.0±0.3a	4.56±0.24a	37.3±1.1a	5.92±0.44a
	喷硒	38.1±0.5a	4.70±0.42a	36.6±1.5a	5.94±0.56a
生选 6 号 Shengxuan 6	对照	37.7±0.9a	4.70±0.44a	35.4±0.6a	5.77±0.67a
	喷硒	38.9±0.8a	4.64±0.26a	36.4±0.4a	6.00±0.62a

注:不同小写字母表示同一品种对照和喷硒处理间差异显著($P<0.05$)。

Note: Different lowercase letters indicate significant difference at 0.05 level between the control and the Se foliar spray kernel sample for each tested variety.

4 结论

喷施亚硒酸钠叶面肥可显著提高小麦籽粒的总硒、无机硒和有机硒含量。不同品种小麦对总硒、无机硒和有机硒含量的积累能力不同。小麦籽粒制粉后,各粉路的总硒、无机硒和有机硒含量不同,通过麸皮损失的硒含量在品种间也存在差异。进一步筛选高硒积累能力的小麦品种,开展富硒面粉及制粉副产品加工利用是下阶段研究工作的重要内容之一,这对富硒小麦的加工利用具有重要的指导作用。

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Effects of Selenium Foliar Spray on Selenium Distribution in Milling Fractions in Common Wheat

ZHANG Pingping* MA Hongxiang YAO Jinbao ZHANG Peng
(*Institute of Food Crops, Jiangsu Academy of Agricultural Sciences/Jiangsu Collaborative Innovation Center for Modern Crop Production, Nanjing, Jiangsu* 210014)

Abstract: To clarify effect of Selenium foliar spray on Selenium concentration in wheat kernel and milling fractions foliar spray with 0.017% Na_2SeO_3 aqueous solution at the jointing-heading growth stage were applied in four wheat varieties. The concentrations of total Se, organic Se, and inorganic Se in kernel and milling fractions (MLU 202 experiment mill) were determined. The assimilation and distribution of the three Se forms in kernel and milling fractions were affected by genotype. Foliar spray increased total Se concentration in wheat grains by 26.4 to 35.8 times in four wheat varieties, and did not significantly change kernel yield. The Se concentration in the milling fractions followed the order of shorts>bran>Grinding powder>Heart flour>Series powder. Hard wheat lost less Se than soft wheat did as a result of the higher straight flour yield in hard wheat. Se lost in controls and Se foliar spray samples were 53.0% to 69.3% and 36.7% to 44.5%, respectively. Concentration of organic Se was higher than that of inorganic Se in all milling fractions of control samples, and the opposite result was observed in Se foliar spray samples except for the shorts of Ningmai 20. The results of Se distribution in kernel and milling fractions in this study play an important guiding role in the processing and utilization of Se enriched wheat.

Keywords: selenium foliar spray, wheat kernel, flour, selenium concentration