Journal of Plant Nutrition

ISSN: 0190-4167 (Print) 1532-4087 (Online) Journal homepage: http://www.tandfonline.com/loi/lpla20

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To cite this article: A. L. Singh & V. Chaudhari (2015) Zinc Biofortification in Sixty Groundnut Cultivars Through Foliar Application of Zinc Sulphate, Journal of Plant Nutrition, 38:11, 1734-1753, DOI: 10.1080/01904167.2015.1042165

To link to this article: http://dx.doi.org/10.1080/01904167.2015.1042165

Accepted author version posted online: 18 May 2015.

Journal of Plant Nutrition, 38:1734–1753, 2015

ISSN: 0190-4167 print / 1532-4087 online
DOI: 10.1080/01904167.2015.1042165

ZINC BIOFORTIFICATION IN SIXTY GROUNDNUT CULTIVARS THROUGH FOLIAR APPLICATION OF ZINC SULPHATE

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□ *A field experiment with 60 groundnut cultivars, in a calcareous soil having 1.20 mg kg^{-1} available zinc (Zn), foliar application of 0.2% aqueous solution of zinc sulphate thrice at 40, 55 and 70 days at 500, 500 and 1000 L ha^{-1}, respectively, increased the number of pods, pod yield, shelling and 100 seed mass and seed zinc (Zn) content, significantly. The seeds Zn content in groundnut cultivars ranged 38–70 mg kg^{-1} with an average of 48 mg kg^{-1} without Zn and 58 mg kg^{-1} with Zn. Foliar Zn application increased 22% Zn in seed. This increase was more than 10% in 48 out of 60 cultivars. The cultivars GG 7, GG 20, Tirupati 4, DH 8, JSP 19, TKG 19 A, CSMG 884 and S 206 showed > 50 mg kg^{-1} Zn, > 10% increase in seed Zn with Zn application and > 250 g m^{-2} pod yield.*

Keywords: biofortification of Zn, groundnut, foliar Zn application, Zn responsive cultivars, pod yield, 100-seed mass, seed Zn content

INTRODUCTION

The groundnut (*Arachis hypogaea* L.) is an important food legume crop of the world grown on about 24 million hectare (ha) of land under different agro-climatic regions in Asian (11.5 m ha), African (11.5 m ha) and North and South American (1.1 m ha) countries and on large scale mainly in India, China, Nigeria, USA, Myanmar, Indonesia, Sudan, Senegal, Argentina and Vietnam. In India alone it is grown on about 6.5 m ha. Although the average groundnut productivity of the world is around 1500 kg ha^{-1}, it is less than 1000 kg ha^{-1} in more than 50% of the groundnut growing countries due to vagaries of weather conditions and poor soil fertility. However, because of its high-energy, protein and mineral contents at a comparatively low price, the demand of groundnut, as food crop, is increasing worldwide (Singh, 2011).

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Zinc (Zn) is an essential nutrient for plant and human health and its deficiency affects billions of people, hampering growth, development, and immune systems. About two billion people world-wide are at the risk of Zn deficiency, which necessitate a food-based solution to combat Zn malnutrition (WHO, 2002). Presently in India, the Zn deficiency occurs in 48% soils and is expected to increase upto 63% by the year 2025 (Singh, 2009). As a result the Zn content in edible parts is decreasing and may have a strong impact on human health. Biofortification of crops by enriching micronutrient in seeds is a better option for providing a sustainable solution to zinc deficiency in food. The biofortification strategies for the crops are, mineral fertilization, screening, breeding and transgenic approaches and intercropping systems increasing zinc content in the seeds (Cakmak et al., 2010; Lal and Singh, 2007; Singh et al., 2011a, 2011b; Zuo and Zhan, 2009).

Groundnut is a good source of Zn (Singh, 2007; Singh et al., 2011a), the seeds of which are eaten after roasting, frying, salting or boiling and in many preparations and confectionery products (Singh, 2011). However, in India, as the groundnut crop is mostly grown on marginal soil where its productivity, shelling outturn and 100 seed mass as well Zn concentration in seed is low, leading to less per-capita availability of groundnut and Zn (Singh, 2004, 2011; Singh and Basu, 2005; Singh et al., 2004). High Zn density groundnuts may be a solution to ensure adequate level of Zn intake which necessitate increasing of Zn concentration of seed through fortification and selection of high Zn density genotypes (Lal and Singh, 2007; Singh et al., 2011a, 2011b). Extensive research demonstrated the role of Zn fertilizers in increasing the Zn density of grain in cereals, suggesting that wherever fertilizers are available, making full use of Zn fertilizers can provide an immediate and effective option to increase grain Zn concentration, and productivity under soil conditions showing Zn deficiency (Cakmak et al., 2010). However, such studies are lacking in groundnut. Thus an effort was made to increase the seed Zn content in a number of groundnut cultivars through foliar application of zinc sulfate. As India has a diverse climate and a number of groundnut cultivars are grown, 60 high yielding cultivars were taken, to study the influence of foliar spray of zinc sulfate on pod and haulm yields, plant height, number of pods, shelling outturn, 100 seed mass and oil contents along with their effect on seed Zn content.

MATERIALS AND METHODS

Field experiments were conducted, during two consecutive dry seasons of the year 2010 and 2011 at the Directorate of Groundnut Research, Junagadh, India in a medium black, calcareous [10% calcium carbonate ($CaCO_3$)] clayey soil with 7.9 pH, 1.31% organic carbon, 850 mg kg^{-1} total nitrogen

(N), 10 mg kg^{-1} available phosphorus (Olsen P), 12 mg kg^{-1} heat soluble sulfur (available S), 4.1, 32, 1.20 and 3.30 mg kg^{-1} diethylentriaminepentaacetic acid (DTPA) extractable iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu), respectively and 0.76 mg kg^{-1} water extractable boron (B). The field was prepared and 10 cm deep furrows were opened at 45 cm spacing. Sixty groundnut cultivars were grown under two treatments, control and foliar application of Zn in two replicates. These cultivars, each in one row plots of 5 m length, were sown at 10 cm spacing in two sets one for control and another for foliar application of zinc in a factorial randomized block design. A basal dose of 40 kg N and 33 kg P ha^{-1} as diammonium phosphate and urea, 50 kg potassium (K $ha^{-1)}$ as muriate of potash and 30 kg S ha^{-1} as elemental sulphur were mixed in the soil before sowing and 500 kg ha^{-1} gypsum mixed in the soil at flowering. The crop was grown under recommended package of practices with proper plant protection during the cropping season. For foliar Zn treatment, the aqueous solution of 0.2% zinc sulfate was applied on the groundnut foliage, thrice at 40, 55 and 70 DAE (days after emergence) at 500, 1000 and 1000 L ha^{-1}, respectively. Thus a total of 5 kg ha^{-1} zinc sulfate containing 1.13 kg Zn was applied. The crop was harvested at maturity, dried in Sun for a week and pod and haulm yields, shelling out turn and 100-seed mass recorded. Five plants from each plot were uprooted randomly at maturity and plant height and numbers of pods per plant were recorded. From these plant samples the oven-dried leaf and seed tissues were ground to a fine powder and analyzed for Zn contents using atomic absorption spectrophotometer. All the data were analyzed statistically.

The groundnut cultivars, with and without Zn treatment, were arranged for their Zn content in seed and categorized into high (above 50 mg kg^{-1} Zn) and low (less than 50 mg kg^{-1} Zn) Zn density cultivars with high (>20%), medium(10–20%), and low (<10%), response to Zn application.

RESULTS AND DISCUSSIONS

Plant Height, Number of Pods, and Pod and Haulm Yields

There was a large variation in plant height, number of pods and pod and haulm yields among the 60 groundnut cultivars studied (Table 1). Foliar application of Zn decreased the plant height and haulm yield, but increased the number of pods significantly during both the years. The mean plant height of 60 groundnut cultivars was 47 cm during the year 2010 and 50 cm during 2011 in control plot, which with application of Zn decreased to 45 and 48 cm, respectively (Table 1). The plant height for control and Zn treatment in different cultivars ranged 32–56 cm during 2010 and 37–68 cm during 2011. Similarly, the haulm yield in groundnut cultivars ranged from 203–670 g m^{-2} during 2010 and 241–760 g m^{-2} during 2011. The haulm

TABLE 1 Influence of Zn spray on plant height, number of pods and haulm yield of 60 groundnut cultivars during two years

		2010									2011								
		Plant ht. (cm)			Pods plant^{-1}			Haulm yield (g m^{-2})			Plant ht. (cm)			Pods plant^{-1}			Haulm yield (g m^{-2})		
SN	Groundnut cultivar	C	Zn	M	C	Zn	M	C	Zn	M	C	Zn	M	C	Zn	M	C	Zn	M
1	SB XI	48	47	48	14	13	14	431	290	361	52	48	50	15	17	16	554	417	485
2	SG 99	45	41	43	11	12	11	394	380	387	61	52	57	14	15	15	633	551	592
3	SG 84	42	37	40	8	13	10	305	289	297	45	44	45	20	27	24	285	245	265
4	JL 24	49	49	49	9	15	12	433	430	431	64	50	57	14	15	15	482	438	460
5	CO 1	48	55	52	14	17	15	462	315	389	62	60	61	21	26	24	392	392	392
6	VRI 2	53	51	52	9	11	10	303	307	305	46	47	47	18	22	20	608	564	586
7	CO 2	48	50	49	11	13	12	305	275	290	52	50	51	21	22	21	504	410	457
8	GG 2	52	47	50	11	13	12	415	301	358	46	45	46	15	17	16	338	299	319
9	GG 7	52	40	46	13	11	12	370	423	396	41	43	42	12	15	13	254	329	292
10	GG 12	52	45	49	9	10	9	407	492	449	50	41	46	17	19	18	417	312	364
11	GG 20	48	48	48	14	18	16	439	563	501	46	52	49	23	27	25	455	499	477
12	LGN 2	38	37	38	11	12	12	390	355	373	42	42	42	21	15	18	368	342	355
13	MH 1	54	42	48	9	11	10	360	385	373	52	47	50	18	17	18	303	284	294
14	RS 1	53	52	53	9	16	12	473	402	437	57	50	54	22	23	22	632	554	593
15	JL 501	48	42	45	9	12	10	362	420	391	38	49	44	16	17	16	384	418	401
16	ICG (FDRS) 4	52	49	51	12	11	11	264	258	261	48	55	52	17	16	17	641	604	622
17	S 230	49	52	51	12	15	13	431	452	442	47	57	52	21	30	25	552	610	581
18	R 8808	43	45	44	11	13	12	181	266	223	46	53	50	24	28	26	551	508	529
19	S 206	48	48	48	13	14	13	241	236	239	49	57	53	20	24	22	417	363	390
20	UF 70-103	45	48	47	8	12	10	408	421	415	40	43	42	18	19	19	519	428	473
21	RG 141	52	52	52	16	17	17	310	304	307	56	53	55	16	25	21	352	474	413
22	Tirupati 3	57	55	56	8	10	9	448	460	454	60	58	59	23	24	23	680	661	670
23	Tirupati 4	47	46	47	13	11	12	440	376	408	60	58	59	17	13	15	500	426	463
24	Kadiri 3	54	56	55	10	13	12	372	311	341	62	57	60	25	20	23	446	404	425
25	ICGS 5	52	44	48	15	13	14	374	349	361	60	62	61	25	30	28	515	534	524

(Continued on next page)

TABLE 1 Influence of Zn spray on Plant height, number of pods and haulm yield of 60 groundnut cultivars during two years *(Continued)*

		2010									2011								
		Plant ht. (cm)			Pods plant^{-1}			Haulm yield (g m^{-2})			Plant ht. (cm)			Pods plant^{-1}			Haulm yield (g m^{-2})		
SN	Groundnut cultivar	C	Zn	M	C	Zn	M	C	Zn	M	C	Zn	M	c	Zn	M	C	Zn	M
26	ICGS 76	42	42	42	12	15	14	380	444	412	52	55	54	20	18	19	605	569	587
27	TPG 41	33	37	35	9	12	11	414	368	391	45	35	40	25	20	23	512	451	482
28	Tirupati 2	45	48	47	10	16	13	296	301	298	46	43	45	24	25	25	514	477	495
29	CSMG 884	49	49	49	7	10	9	430	506	468	61	62	62	27	32	30	626	541	584
30	TG 17	38	36	37	17	13	15	314	256	285	38	43	41	24	12	18	535	465	500
31	B 95	48	50	49	10	12	11	462	495	478	45	46	46	30	31	30	601	500	550
32	DRG 17	48	46	47	14	12	13	378	319	349	42	46	44	19	17	18	386	361	374
33	R 9251	46	46	46	8	16	12	499	383	441	48	43	46	22	21	21	437	374	406
34	RS 138	48	47	48	14	15	14	689	652	670	51	45	48	21	16	19	639	521	580
35	TG 26	33	31	32	11	12	12	210	196	203	37	40	39	23	26	24	263	218	241
36	TKG 19 A	46	44	45	12	11	12	443	408	426	52	43	48	15	17	16	680	497	589
37	DH 8	57	49	53	11	7	9	346	199	273	44	42	43	10	11	10	443	343	393
38	JL 220	50	40	45	10	13	12	281	323	302	37	38	38	11	13	12	259	275	267
39	TAG 24	41	36	39	13	13	13	212	199	206	36	38	37	19	17	18	256	226	241
40	ALR 3	57	45	51	13	14	14	639	476	558	49	53	51	19	21	20	706	558	632
41	ALR 2	56	42	49	12	14	13	469	209	339	66	70	68	22	27	25	536	656	596
42	HNG 10	48	44	46	10	13	12	417	354	385	46	44	45	22	32	27	290	307	299
43	DSG 1	41	43	42	10	10	10	413	380	396	44	42	43	24	22	23	549	516	532

44	Gangapuri	35	30	33	11	12	12	235	184	210	45	39	42	18	18	18	329	320	324
45	Chitra	43	50	47	9	10	9	349	336	343	53	50	52	15	23	19	473	601	537
46	Girnar 2	36	33	35	10	8	9	287	230	258	39	40	40	12	16	14	365	351	358
47	TG 37 A	42	37	40	18	15	17	483	351	417	46	47	47	19	24	21	276	307	291
48	DRG 12	42	38	40	14	11	12	447	353	400	53	50	52	19	24	22	456	623	540
49	JSP 19	46	47	47	9	14	11	544	385	465	47	44	46	16	20	18	615	477	546
50	K 134	52	52	52	12	11	12	608	374	491	53	51	52	18	17	18	391	361	376
51	BAU 13	53	51	52	7	10	8	626	560	593	56	54	55	16	18	17	527	480	504
52	M 13	45	47	46	15	16	16	584	418	501	51	48	50	16	23	20	371	440	406
53	M 145	45	45	45	10	10	10	466	264	365	50	45	48	19	26	23	538	563	551
54	M 197	47	48	48	14	17	16	449	366	408	55	48	52	19	24	22	603	528	566
55	M 522	40	39	40	7	10	8	395	234	314	41	35	38	23	22	23	566	456	511
56	CSMG 84-1	42	46	44	16	12	14	613	397	505	44	41	43	22	24	23	480	434	457
57	ICGV 86590	40	38	39	11	9	10	260	260	260	45	41	43	14	18	16	396	430	413
58	ICGV 86325	49	48	49	14	12	13	372	330	351	56	45	51	20	18	19	713	348	531
59	ICGV 86031	51	52	52	16	17	17	353	402	377	61	58	60	21	27	24	511	501	506
60	ICGV 88448	46	44	45	8	9	8	446	358	402	60	55	58	20	23	21	578	574	576
	Mean	47	45	46	11	13	12	402	355	379	50	48	49	19	21	20	475	412	463
	SD	5.8	5.9	5.4	2.6	2.5	2.2	108	97	94	7.6	7.3	7.0	4.0	5.2	4.2	126	111	111
	LSD (0.05)																		
	Treatment		1.7			1.2			45			1.6			1.5			30	
	Cultivars		9.3			6.6			NS			8.7			8.2			164	
	Interactions		NS			NS			NS			NS			NS			NS	

C is control, Zn is foliar spray of Zn, M is mean values, SD is standard deviation and NS is not significant.

yield in control plot which was 402 and 475 g m^{-2}, respectively during 2010 and 2011, decreased to 355 and 412 g m^{-2} causing 12 and 13% reductions, respectively due to Zn applications. On the other hand the mean number of pods $plant^{-1}$ were 11 and 19 in control plots which with application of Zn increased to 13 and 21 pods $plant^{-1}$ during 2010 and 2011, respectively. The number of pods $plant^{-1}$ ranged from 8-17 during 2010 and 10-30 during 2011. There was no interaction of Zn treatment and cultivars on plant height, pod numbers and haulm yield.

The pod yield of groundnut cultivars ranged from 150–557 g m^{-2} with a mean value of 269 g m^{-2} during the year 2010 and ranged 192–531 g m^{-2} with a mean of 344 g m^{-2} during 2011 (Table 2). Application of Zn increased the pod yield of groundnut cultivars during both the years. The mean pod yield of control plot was 258 g m^{-2} and 332 g m^{-2} which with application of Zn increased to 280 g and 356 g m^{-2} during 2010 and 2011, respectively. Thus there was an increase of 9% and 7% in pod yield during those years. The pooled analysis of pod yield data for two years revealed that the pod yield in groundnut cultivars ranged from 201–514 g m^{-2} with a mean value of 306 g m^{-2}. Overall there was 8% increase in pod yield due to Zn application as the mean pod yield of groundnut cultivars in control plot which was 295 g m^{-2} increased to 318 g m^{-2} with Zn. However, the Zn application did not have any interaction effect with groundnut cultivars on pod yields.

In India about 50% of the groundnut soils show Zn deficiency, a most common in calcareous soils causing up to 20% yield-losses where Zn application is essential for proper growth and development (Singh, 2004, 2007; Singh et al., 2004; Singh and Basu, 2005). The iron-deficiency chlorosis is also a problem of calcareous soil, where foliar application of a iron sulphate is recommended (Singh and Dayal, 1992; Singh et al., 2004). Application of Zn increases the chlorophyll, pod number, yield and fertilizer use efficiency (Singh, 2007). In a Typic Chromustert soil at Parbhani, India, groundnut cvs. M 13, JL 24, L 33 and K-4-11 the pod and haulm yields, 100-seed mass, root weight, root volume and root density increased and were highest with 20 kg ha^{-1} zinc sulfate ($ZnSO_4$) (Malewar et al., 1993). In a study at Junagadh the Zn applied at 5 and 10 kg ha^{-1} in caster, increased available Zn in soil and seed yield by 9.5 and 11.1% and stalk yield by 9.1 and 11.2%, respectively (Mathukia and Khanpara, 2008). In the present study, the data clearly indicated that foliar application of Zn did not allow excess growth as a result both plant height and haulm were decreased, but increased the mobilization as well translocation of photosynthates and hence both the number of pods and pod yield increased due to Zn. The Zn applied through foliar application is readily absorbed by the leaves and further translocated to other parts, hence increased pod yield. Also Zn acted as a balancing nutrient and checked the excessive growth of the crop and reduced both plant height and haulm yield.

TABLE 2 Influence of Zn spray on pod yield and seed Zn concentration of groundnut cultivars during 2010 and 2011

		Pod yield (g m^{-2})									Zn content (mg kg^{-1})											
		2010			2011			Pooled data			2010				2011				Pooled data			
SN	Groundnut Cultivar	C	Zn	M	C	Zn	M	C	Zn	M	C	Zn	M	Res	C	Zn	M	Res	C	Zn	M	Res
1	SB XI	196	244	220	304	329	316	250	286	268	63	69	66	10	69	71	70	3	66	70	68	6
2	SG 99	294	370	332	482	475	479	388	422	405	42	51	47	21	40	72	56	80	41	62	51	50
3	SG 84	233	258	245	354	349	351	293	303	298	63	65	64	3	60	63	62	5	62	64	63	4
4	JL 24	204	259	231	332	349	340	268	304	286	56	64	60	14	60	74	67	23	58	69	64	19
5	CO 1	196	252	224	280	311	296	238	282	260	52	63	58	21	50	61	56	22	51	62	57	22
6	VRI 2	213	265	239	341	349	345	277	307	292	41	57	49	39	56	68	62	21	49	63	56	29
7	CO 2	182	232	207	288	314	301	235	273	254	45	62	54	38	56	62	59	11	51	62	56	23
8	GG 2	301	313	307	257	269	263	279	291	285	55	70	63	27	51	70	61	37	53	70	62	32
9	GG 7	323	416	369	259	301	280	291	358	325	59	69	64	17	60	91	76	52	60	80	70	34
10	GG 12	151	179	165	219	253	236	185	216	201	39	41	40	5	55	58	57	5	47	50	48	5
11	GG 20	553	562	557	430	511	470	491	536	514	60	62	61	3	52	62	57	19	56	62	59	11
12	LGN 2	306	318	312	334	333	333	320	326	323	39	55	47	41	39	53	46	36	39	54	47	38
13	MH 1	370	360	365	185	248	217	278	304	291	50	65	58	30	59	74	67	25	55	70	62	28
14	RS 1	192	242	217	299	371	335	246	306	276	57	65	61	14	39	70	55	79	48	68	58	41
15	JL 501	323	378	350	334	319	326	328	349	338	42	62	52	48	39	74	57	90	41	68	54	68
16	ICG (FDRS) 4	243	254	248	218	244	231	230	249	240	44	56	50	27	37	47	42	27	41	52	46	27
17	S 230	347	328	337	351	404	378	349	366	357	58	60	59	3	33	54	44	64	46	57	51	25
18	R 8808	275	268	271	241	267	254	258	267	263	35	42	39	20	39	50	45	28	37	46	42	24
19	S 206	371	394	383	266	351	309	319	373	346	48	60	54	25	52	70	61	35	50	65	58	30
20	UF 70-103	289	304	296	296	367	332	293	336	314	40	53	47	33	40	70	55	75	40	62	51	54
21	RG 141	290	284	287	247	268	258	268	276	272	38	56	47	47	56	53	55	-5	47	55	51	16
22	Tirupati 3	293	280	287	167	216	192	230	248	239	49	60	55	22	52	54	53	4	51	57	54	13
23	Tirupati 4	292	322	307	314	347	331	303	335	319	51	68	60	33	57	66	62	16	54	67	61	24
24	Kadiri 3	281	271	276	389	382	386	335	327	331	39	55	47	41	39	42	41	8	39	49	44	24
25	ICGS 5	330	365	348	503	559	531	417	462	439	45	57	51	27	35	52	44	49	40	55	47	36

(Continued on next page)

TABLE 2 Influence of Zn spray on pod yield and seed Zn concentration of groundnut cultivars during 2010 and 2011 *(Continued)*

		Pod yield ($g\ m^{-2}$)									Zn content ($mg\ kg^{-1}$)											
		2010			2011			Pooled data			2010				2011				Pooled data			
SN	Groundnut Cultivar	C	Zn	M	C	Zn	M	C	Zn	M	C	Zn	M	Res	C	Zn	M	Res	C	Zn	M	Res
26	ICGS 76	340	374	357	426	431	429	383	403	393	43	46	45	7	39	62	51	59	41	54	48	32
27	TPG 41	334	339	337	436	470	453	385	405	395	35	56	46	60	34	46	40	35	35	51	43	48
28	Tirupati 2	237	263	250	409	445	427	323	354	339	44	51	48	16	54	64	59	19	49	58	53	17
29	CSMG 884	325	334	330	449	527	488	387	431	409	53	60	57	13	51	60	56	18	52	60	56	15
30	TG 17	262	297	279	346	426	386	304	361	333	46	64	55	39	37	41	39	11	42	53	47	27
31	B 95	320	343	332	344	337	340	332	340	336	48	59	54	23	35	45	40	29	42	52	47	25
32	DRG 17	220	227	223	371	355	363	295	291	293	32	42	37	31	35	44	40	26	34	43	38	28
33	R 9251	298	362	330	318	365	341	308	364	336	59	54	57	-8	49	54	52	10	54	54	54	0
34	RS 138	189	190	189	318	320	319	254	255	254	63	64	64	2	31	39	35	26	47	52	49	10
35	TG 26	186	240	213	311	359	335	248	299	274	54	55	55	2	33	52	43	58	44	54	49	23
36	TKG 19 A	250	315	282	510	499	505	380	407	393	57	69	63	21	48	53	51	10	53	61	57	16
37	DH 8	228	292	260	352	380	366	290	336	313	59	68	64	15	60	74	67	23	60	71	65	19
38	JL 220	204	209	206	230	247	238	217	228	222	57	63	60	11	57	71	64	25	57	67	62	18
39	TAG 24	191	183	187	231	224	228	211	204	208	63	65	64	3	38	55	47	45	51	60	55	19
40	ALR 3	187	223	205	391	377	384	289	300	295	58	62	60	7	39	56	48	44	49	59	54	22
41	ALR 2	233	266	250	304	297	301	269	281	275	48	47	48	-2	52	54	53	4	50	51	50	1
42	HNG 10	229	264	246	439	433	436	334	348	341	51	61	56	20	36	45	41	25	44	53	48	22
43	DSG 1	240	229	234	276	315	296	258	272	265	46	55	51	20	45	50	48	11	46	53	49	15
44	Gangapuri	162	154	158	242	287	264	202	220	211	45	55	50	22	40	57	49	43	43	56	49	32
45	Chitra	296	288	292	313	372	342	304	330	317	52	53	53	2	38	44	41	16	45	49	47	8

46	Girnar 2	294	284	289	394	430	412	344	357	350	35	40	38	14	34	50	42	47	35	45	40	30
47	TG 37 A	225	266	246	241	287	264	233	276	255	45	66	56	47	49	73	61	49	47	70	58	48
48	DRG 12	231	269	250	310	303	306	271	286	278	51	52	52	2	47	54	51	15	49	53	51	8
49	JSP 19	347	335	341	441	436	438	394	386	390	54	64	59	19	63	73	68	16	59	69	64	17
50	K 134	174	179	177	230	250	240	202	215	208	59	70	65	19	42	76	59	81	51	73	62	45
51	BAU 13	150	182	166	334	372	353	242	277	259	62	70	66	13	48	58	53	21	55	64	60	16
52	M 13	198	244	221	248	290	269	223	267	245	60	63	62	5	49	53	51	8	55	58	56	6
53	M 145	175	194	185	237	235	236	206	215	210	62	63	63	2	45	49	47	9	54	56	55	5
54	M 197	236	251	244	298	348	323	267	299	283	43	48	46	12	47	57	52	21	45	53	49	17
55	M 522	273	272	272	392	406	399	332	339	335	49	60	55	22	32	46	39	44	41	53	47	31
56	CSMG 84-1	239	257	248	317	325	321	278	291	285	43	46	45	7	45	46	46	2	44	46	45	5
57	ICGV 86590	319	308	313	408	396	402	363	352	358	49	53	51	8	54	56	55	4	52	55	53	6
58	ICGV 86325	139	161	150	381	436	408	260	298	279	48	47	48	-2	31	46	39	48	40	47	43	18
59	ICGV 86031	201	193	197	294	339	316	247	266	257	47	53	50	13	33	75	54	127	40	64	52	60
60	ICGV 88448	278	272	275	487	517	502	383	394	389	54	55	55	2	32	46	39	44	43	51	47	17
	Mean	258	280	269	332	356	344	295	318	306	50	58	54	17	45	58	52	29	48	58	53	22
	SD	72	71	70	81	81	80	62	65	63	8	8	7		10	11	9		7	8	7	
	LSD (0.05)																					
	Treatment		19			21			20			2.2					3			2		
	Cultivars		104			115			111			12					16			11		
	Interactions		NS			NS			NS			NS					NS			16		

C is control, Zn is foliar spray of Zn, M is mean values and Res is% increase in Zn treatment over control

Shelling Outturn, 100 Seed Mass and Oil Content

There was a large genetic variation in the shelling outturn, 100 seed mass and oil content among groundnut cultivars. With foliar application of Zn, the shelling outturn and 100 seed mass in groundnut cultivars increased, but the oil content decreased significantly (Table 3). The range of shelling percentage in groundnut cultivars was 65–81% with a mean value of 73% during the year 2010 and 63–79% with a mean value of 73% during 2011. Similarly the range of the 100 seed mass in groundnut cultivars was 35–82 g with a mean value of 47 g during 2010 and 34–96 g with a mean value of 50 g during 2011. The mean shelling percentage in control was 72% which with Zn application increased to 74%. The mean 100 seed mass in control plot was 46 g during 2010 and 49 g during 2011 which with application of Zn increased to 48 and 51 g, respectively during those years. Thus there was 3% increase in shelling outturn and 2% increase in 100 seed mass due to Zn application. There was no interaction of Zn application and groundnut cultivars on these parameters. Our earlier study has demonstrated that in calcareous soil, application of Zn is essential to enhance yield attributes in groundnut (Singh, 2007; Singh et al., 2004). Here it was clearly demonstrated that foliar application of Zn increased shelling out turn and 100-seed mass.

The oil content in groundnut cultivars ranged from 43–51% with a mean of 48%. Application of Zn decreased the oil content in groundnut cultivars by 2% as a result the mean oil content in groundnut cultivars which was 49% in control plot decreased to 47% with Zn treatment (Table 3).

Zinc Concentrations in Seed

The Zn concentrations in groundnut seeds when analyzed, there was a large variation observed among the groundnut cultivars. The Zn concentrations in seeds of 60 groundnut cultivars ranged from 32–63 mg kg^{-1} Zn with a mean value of 50 mg kg^{-1} Zn during 2010, which with foliar application of Zn increased to 41–70 and 58 mg kg^{-1}, respectively indicating a very good response of Zn application (Table 2). Similarly during 2011, the Zn concentrations in seeds of groundnut cultivars ranged from 31–69 mg kg^{-1} Zn with a mean value of 45 mg kg^{-1} Zn, which with foliar application of Zn increased to 39-91 and 58 mg kg^{-1}, respectively again indicating a very good response of Zn application. When the data of the control and Zn treatment were combined, the range of Zn content among groundnut cultivars were 37–66 mg kg^{-1} with a mean value of 54 mg kg^{-1} during 2010 and 35–76 mg kg^{-1} with a mean value of 53 mg kg^{-1} during 2011 (Table 2).

Application of zinc sulfate increased the Zn content in seed of most of the groundnut cultivars significantly, though a few did not respond to Zn application. The response of foliar application of Zn in increasing the seed Zn content of groundnut cultivars ranged from -8% to 60% with a mean

TABLE 3 Influence of Zn spray on shelling outturn, 100 seed mass and oil contents of groundnut cultivars during two years

		Year 2010						Year 2011								
		Shelling (%)			100-seed wt (g)			Shelling (%)			100 seed wt. (g)			Oil (%)		
SN	Groundnut cultivar	C	Zn	M	C	Zn	M	C	Zn	M	C	Zn	M	C	Zn	M
1	SB XI	79	82	81	36	36	36	76	75	75	42	39	41	48	47	47
2	SG 99	77	73	75	52	49	50	71	77	74	57	64	60	51	49	50
3	SG 84	71	76	74	38	35	36	66	72	69	33	35	34	47	47	47
4	JL 24	74	71	73	44	43	43	71	80	76	46	45	46	47	45	46
5	CO 1	73	81	77	43	44	43	75	78	76	36	35	36	50	46	48
6	VRI 2	73	71	72	42	43	42	75	74	75	45	44	45	49	47	48
7	CO 2	71	83	77	39	41	40	72	74	73	41	40	40	49	49	49
8	GG 2	76	77	76	40	44	42	79	78	79	43	44	43	47	47	47
9	GG 7	75	77	76	48	56	52	72	73	72	50	52	51	48	46	47
10	GG 12	65	74	69	33	39	36	72	71	72	42	44	43	50	47	48
11	GG 20	75	74	74	51	52	52	72	76	74	62	70	66	49	47	48
12	LGN 2	75	75	75	42	44	43	71	76	73	51	47	49	48	46	47
13	MH 1	72	74	73	40	40	40	71	72	71	37	35	36	44	44	44
14	RS 1	68	70	69	46	43	45	72	73	73	46	49	48	49	44	46
15	JL 501	76	75	75	39	39	39	74	77	76	44	43	44	46	47	47
16	ICG (FDRS) 4	68	69	68	40	44	42	65	67	66	36	36	36	50	48	49
17	S 230	74	76	75	46	53	49	72	75	73	45	47	46	48	46	47
18	R 8808	78	76	77	35	37	36	75	76	76	36	38	37	48	46	47
19	S 206	79	80	79	41	41	41	74	75	74	35	39	37	49	47	48
20	UF 70-103	66	64	65	46	46	46	76	73	74	54	53	53	50	48	49
21	RG 141	75	74	74	37	38	37	70	68	69	37	39	38	46	47	47
22	Tirupati 3	69	78	74	43	41	42	70	69	70	48	54	51	53	49	51
23	Tirupati 4	75	72	74	50	48	49	73	74	74	45	45	45	48	45	46
24	Kadiri 3	72	73	72	50	50	50	72	76	74	46	41	43	51	48	49

(Continued on next page)

TABLE 3 Influence of Zn spray on shelling outturn, 100 seed mass and oil contents of groundnut cultivars during two years *(Continued)*

25	ICGS 5	76	81	78	39	39	39	76	77	76	44	42	43	48	46	47
26	ICGS 76	76	81	79	54	55	54	75	76	75	57	63	60	49	47	48
27	TPG 41	76	73	74	63	66	65	77	77	77	62	64	63	51	49	50
28	Tirupati 2	76	75	75	37	38	37	72	76	74	37	40	38	49	46	47
29	CSMG 884	70	69	70	64	66	65	71	72	71	61	69	65	50	47	48
30	TG 17	72	69	70	47	48	47	75	77	76	55	63	59	49	50	49
31	B 95	73	67	70	69	78	74	71	70	70	65	67	66	46	47	47
32	DRG 17	77	77	77	40	39	39	75	77	76	51	56	54	48	51	50
33	R 9251	78	73	75	37	37	37	71	76	73	38	36	37	45	47	46
34	RS 138	72	68	70	47	49	48	70	74	72	44	46	45	49	50	50
35	TG 26	75	80	77	37	34	35	72	71	71	35	37	36	45	43	44
36	TKG 19 A	68	70	69	61	61	61	70	76	73	53	56	55	45	49	47
37	DH 8	70	73	72	49	49	49	67	70	68	46	44	45	46	48	47
38	JL 220	69	72	70	48	49	48	69	67	68	52	49	51	49	48	49
39	TAG 24	69	71	70	33	37	35	76	77	76	41	44	42	45	42	43
40	ALR 3	68	71	69	41	44	42	63	65	64	42	45	44	46	51	49
41	ALR 2	67	73	70	39	38	38	74	79	77	33	42	37	53	46	49
42	HNG 10	79	73	76	38	47	42	78	80	79	50	50	50	51	47	49
43	DSG 1	67	68	68	50	50	50	67	73	70	51	54	52	49	48	49
44	Gangapuri	76	78	77	33	39	36	75	76	76	42	45	44	47	46	46
45	Chitra	69	73	71	50	52	51	69	67	68	59	56	57	51	49	50

46	Girnar 2	71	73	72	57	59	58	75	75	75	58	55	56	50	50	50
47	TG 37 A	68	70	69	40	40	40	75	76	75	45	53	49	46	46	46
48	DRG 12	78	76	77	46	44	45	76	81	79	49	56	53	49	49	49
49	JSP 19	64	73	69	54	55	54	76	77	76	66	73	69	47	45	46
50	K 134	72	75	73	36	37	37	75	79	77	43	44	43	49	49	49
51	BAU 13	66	67	66	82	82	82	61	65	63	78	88	83	50	48	49
52	M 13	70	75	73	63	66	64	76	75	75	70	63	66	50	48	49
53	M 145	68	75	72	37	43	40	70	73	71	43	46	44	50	49	49
54	M 197	72	74	73	45	46	45	70	76	73	50	56	53	51	46	49
55	M 522	74	72	73	67	72	70	68	69	68	63	68	65	52	47	49
56	CSMG 84-1	70	73	72	56	60	58	67	70	68	53	53	53	51	49	50
57	ICGV 86590	63	68	65	40	42	41	70	72	71	41	44	42	53	47	50
58	ICGV 86325	74	74	74	44	43	43	73	75	74	72	78	75	48	47	48
59	ICGV 86031	75	73	74	49	50	49	74	75	75	42	43	42	49	49	49
60	ICGV 88448	73	68	71	72	73	72	73	66	69	97	95	96	46	47	47
	Mean	72	74	73	46	48	47	72	74	73	49	51	50	49	47	48
	SD	4.1	4.0	3.5	10.4	11.0	10.6	3.6	3.9	3.5	12.0	12.9	12.3	2.0	1.8	1.6
	LSD (0.05)															
	Treatment		1.6			1.4			1.8			1.5			1.7	
	Cultivars		8.7			7.7			9.9			8.2			9.3	
	Interactions		NS			NS			NS			NS			NS	

C is control, Zn is foliar spray of Zn, M is mean values, SD is standard deviation and NS is not significant.

value of 17% increase during 2010 and -5% to 127% increase with a mean value of 29% increase during 2011. The mean Zn content of groundnut seeds were 50 and 45 mg kg^{-1} which with application of Zn increased to 58 and 58 mg kg^{-1} during 2010 and 2011, respectively. Thus overall there was 17 and 29% increase in seed Zn content due to application of Zn in groundnut over control during 2010 and 2011, respectively.

Under normal condition, without any Zn treatment, 29 cultivars showed 50 mg kg^{-1} and more Zn in their seed and 31 cultivars showed less than 50 mg kg^{-1} Zn in their seed during the year 2010, but with foliar application of Zn the number of cultivars showing above 50 mg kg^{-1} Zn in their seed increased to 51 and only 9 cultivars were left with less than 50 mg kg^{-1} Zn. So much so with application of Zn, 30 cultivars showed 60 mg kg^{-1} and above Zn in their seed, the number of which otherwise were only 10 without Zn application during 2010. Similarly during 2011 under normal condition, 22 cultivars showed 50 mg kg^{-1} and more Zn and 38 cultivars showed less than 50 mg kg^{-1} Zn in their seed and with foliar application of Zn the number of cultivars showing above 50 mg kg^{-1} Zn in their seed increased to 46 and only 14 cultivars were left with less than 50 mg kg^{-1} Zn. Also with application of Zn, 26 cultivars showed 60 mg kg^{-1} and above Zn in their seed during 2011, the number of which otherwise were only 4 without Zn application.

When the data for the two years were combined on an average, there was 22% increase in seed Zn content in seed due to foliar application of Zn on groundnut foliage. However, these responses varied with cultivars and there was 1 to 60% increase in seed Zn content over control. The range of seed Zn content varied from 38–70 mg kg^{-1} with a mean value of 53 mg kg^{-1}. The mean seed Zn content of groundnut seed in control plot was 48 mg kg^{-1} which with foliar application of Zn increased to 58 mg kg^{-1}. There were 35 groundnut cultivars showing less than 50 mg kg^{-1} in control plots (without Zn) which with application of Zn were reduced to only 7. Thus application of Zn increased the Zn content in seed of groundnut cultivars and out of 60 groundnut cultivars, 53 cultivars showed more than 50 mg kg^{-1}. This clearly indicated that the groundnut cultivars with low seed Zn are more responsive to foliar application of Zn than the cultivars with high seed Zn. Some of the cultivars not responding to foliar Zn application in increasing seed Zn indicated their genetic makeup. In a preliminary study with several groundnut cultivars 16% increase in the seed Zn content was observed due to foliar application of Zn, though responses varied with cultivars (Singh et al., 2011a). The zinc contents in grains of soyabean cultivars ranged 72–79 mg kg^{-1} (Varsha Rani et al., 2008).

As there was a large variation in seed Zn content of groundnut cultivars and the response of foliar Zn application on groundnut cultivars, these were categorized into various groups (Table 4). Accordingly, based on two years data among the 25 groundnut cultivars having more than 50 mg kg^{-1} Zn in

TABLE 4 Influence of foliar Zn spray on seed Zn content of high and low Zn containing groundnut cultivars (pooled data of two years during dry 2010 and 2011)

	High Zn containing cultivars					Low Zn containing cultivars			
		Zn content (mg kg^{-1}) in seed					Zn content (mg kg^{-1}) in seed		
SN	Cultivars	Control	Zn	% increase over control	SN	Cultivars	Control	Zn	% increase over control
				High response > 20%					
1	GG 7	60	80	34	26	VRI 2	49	63	29
2	MH 1	55	70	28	27	ALR 3	49	59	22
3	Tirupati 4	54	67	24	28	RS 1	48	68	41
4	GG 2	53	70	32	29	TG 37 A	47	70	48
5	CO 1	51	62	22	30	S 230	46	57	25
6	CO 2	51	62	23	31	TG 26	44	54	23
7	K 134	51	73	45	32	HNG 10	44	53	22
8	S 206	50	65	30	33	Gangapuri	43	56	32
		34	TG 17	42	53	27			
					35	B 95	42	52	25
					36	SG 99	41	62	50
					37	ICGS 76	41	54	32
					38	JL 501	41	68	68
					39	ICG (FDRS) 4	41	52	27
					40	M 522	41	53	31
					41	UF 70-103	40	62	54
					42	ICGS 5	40	55	36
					43	ICGV 86031	40	64	60
					44	LGN 2	39	54	38
		45	Kadiri 3	39	49	24			
					46	R 8808	37	46	24
					47	TPG 41	35	51	48
					48	Girnar 2	35	45	30
					49	DRG 17	34	43	28

(Continued on next page)

TABLE 4 Influence of foliar Zn spray on seed Zn content of high and low Zn containing groundnut cultivars (pooled data of two years during dry 2010 and 2011) *(Continued)*

	High Zn containing cultivars					Low Zn containing cultivars			
		Zn content (mg kg^{-1}) in seed					Zn content (mg kg^{-1}) in seed		
SN	Cultivars	Control	Zn	% increase over control	SN	Cultivars	Control	Zn	% increase in over control
Medium response 11–20%									
9	DH 8	60	71	19	50	Tirupati 2	49	58	17
10	JSP 19	59	69	17	51	RG 141	47	55	16
11	JL 24	58	69	19	52	DSG 1	46	49	15
12	JL 220	57	67	18	53	M 197	45	53	17
13	GG 20	56	62	11	54	ICGV 88448	43	51	17
14	BAU 13	55	64	16	55	ICGV 86325	40	47	18
15	TKG 19 A	53	61	16					
16	CSMG 884	52	60	15					
17	Tirupati 3	51	57	13					
18	TAG 24	51	60	19					
Low response < 10%									
19	SB XI	66	70	6	56	DRG 12	49	53	8
20	SG 84	62	64	4	57	GG 12	47	50	5
21	M 13	55	58	6	58	RS 138	47	52	10
22	R 9251	54	54	0	59	Chitra	45	49	8
23	M 145	54	56	5	60	CSMG 84-1	44	46	5
24	ICGV 86590	52	55	6					
25	ALR 2	50	51	2					

their seeds without any application of Zn, 8 groundnut cultivars GG 7, MH 1, Tirupati 4, GG 2, CO 1, CO 2, K 134 and S 206 showed more than 20% increase in seed Zn content with foliar Zn application, 10 cultivars DH 8, JSP 19, JL 24, JL 220, GG 20, BAU 13, TKG 19 A, CSMG 884, Tirupati 3 and TAG 24 showed 10–20% response and 7 cultivars showed less than 10% response in increasing the Zn content. On the other hand, from the remaining 35 groundnut cultivars having less than 50 mg kg^{-1} Zn in their seeds, 24 cultivars showed more than 20% increase in seed Zn content, 6 cultivars showed 10–20% and only 5 cultivars showed less than 10% increase in seed Zn content (Table 4). Thus in general the groundnut cultivars having less than 50 mg kg^{-1} Zn in their seeds showed more response to Zn application in increasing the Zn content in seeds. In India, Zn deficiency a most common in calcareous soils causing up to 20% yield-losses where foliar application of Zn is essential to meet the Zn requirement and also to maintain proper Zn in seed (Singh, 2007; Singh et al, 1993, 2004; Singh and Basu, 2005). In a field study on several groundnut cultivars Singh et al. (2011b) found 17 high Zn density groundnut cultivars having more than 63 mg kg^{-1} Zn in their seeds, 16 low in Zn density with $<$ 51 mg kg^{-1} Zn and 70 cultivars were medium in Zn density with 51–63 mg kg^{-1} Zn in their seeds.

In this study, foliar application of Zn as zinc sulphate increased the Zn content of groundnut seed in most of the cultivars and out of 60 cultivars, 48 showed more than 10% increase in Zn content. Interestingly among the groundnut cultivars with more than 50 mg kg^{-1} Zn in their seeds and showing more than 10% increase in Zn content of seed due to foliar Zn application the 8 cultivars GG 7, GG 20, Tirupati 4, DH 8, JSP 19, TKG 19 A, CSMG 884 and S 206 were high yielding one with more than 300 g m^{-2} pod yield and 6 cultivars CO 1, CO 2, BAU 13, GG 2, MH 1, JL 24 were high yielder with more than 250 g m^{-2} pod yield.

In many micronutrient-deficient regions, wheat is the dominant staple food making up >50% of the diet. Biofortification, or harnessing the powers of plant breeding to improve the nutritional quality of foods, is a new approach being used to improve the nutrient content of a variety of staple crops (Cakmak et al., 2010). Also nitrogen status of plants can have a positive impact on root uptake and the deposition of micronutrients in seed. Several studies have demonstrated the role of Zn fertilizers in increasing the Zn density of grain in cereals, but no studies on groundnut. The present study has clearly demonstrated increase of pod yield and Zn content in seed suggesting that wherever Zn fertilizers are available, making full use of Zn fertilizers can provide an immediate and effective option to increase seed Zn concentration, and productivity on marginal soils with mild to severe Zn deficiencies. The nutrient-efficient species could prevent or mitigate iron and zinc deficiency of plants (Zuo and Zhan, 2009). This study has identified several efficient groundnut cultivars with high Zn mining capacities and also with high performance of foliar application of Zn content resulting in high Zn content in seed.

CONCLUSIONS

Foliar application of zinc sulfate is recommended to increase Zn content of groundnut seed. Further, the groundnut growers are recommended to cultivate Zn responsive, high Zn density and high yielding cultivars such as GG 7, GG 20, Tirupati 4, DH 8, JSP 19, TKG 19 A, CSMG 884 for maximum biofortification of Zn in groundnut seed.

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