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ORIGINAL ARTICLE

Stability performance in wheat grain Zinc and Iron concentrations and grain yield over four environments

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ABSTRACT
This study was carried out in order to determine stability of some traits plant height, days to heading, 1000-grain weight, grain Zinc and Iron concentrations and grain yield of fifty bread wheat genotypes. The experiment was conducted at three environmental conditions during 2016-2017 using randomized block design with two replicates. For all the traits investigated in this study, component of variation due to environment was larger than the component of variation due to genotype and G x E interaction. Different traits like plant height, days to heading, thousand grain weight, grain zinc and iron concentrations and grain yield showed range from 88 to 103 cm, from 84 to 99 days, from 36.9 to 43.8 g, from 26.9 to 44.0 ppm, from 28.8 to 37.7 ppm and from 2.6 to 3.9 kg, respectively over four environments. Two stability parameters were used to develop and evaluation of stable genotypes. The study of genotypic stability showed that the adaptation ability of the three genotypes (404, 439 and 441) for grain Zn concentration and three genotypes (417, 437 and 446) for grain Fe concentration are relatively high and they are more stable than the other genotypes. For grain Zn concentration, these three genotypes also had high mean values compared with mean value of check number 401. Genotypes numbers 404, 439 and 441 were also stable for both grain Zn concentration and grain yield and from these, genotype 441 also had high mean value for respective traits. Similarly genotype number 446 was stable for both grain Fe concentration and grain yield and high mean value for grain yield.
Key words: *Grain Fe, Grain Zinc, Grain yield, Genotype x environment interaction, Stability*

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INTRODUCTION
Wheat is a source of nutrition for 35% of the world population, and presently ranks first among cultivated plants in terms of cultivation area and production [16]. Wheat is used for both human and animal nutrition and plays an important role in the nutrition of rapidly growing populations in the world [32]. Biofortification, which aims to improve micronutrient concentrations and bioavailability in plant based foods through genetic enhancement, is a cost effective way of solving the micronutrient deficiency problem [6, 21]. Knowledge of the difference in the trait among the available germplasm is required for breeding of cereal crops with improved micronutrient concentration [17, 19].
A significant genotype x environment (G × E) interactions have been observed in wild and improved wheat cultivars for both zinc (Zn) and iron (Fe) concentrations [22, 23, 24, 11, 29]. Particularly, in case of grain Zn concentration, environmental conditions complicate the breeding, specially the soil composition [27]. Thus, despite advances in breeding for uptake efficiency or mobilization to the grain, grain Zn concentration is restricted by Zn availability in the soil [22, 23, 10].
Some CIMMYT, Mexico's lines, high in Zn and evaluated in a multilocation trial in India's Eastern Gangetic Plains (EGP), revealed that wheat grain Zn concentrations were highly unstable [15] as the performance of the elite lines varied across locations and years. Cause for greater G × E interaction for grain Zn concentration may be its quantitative inheritance, as reported in maize [18], rice [12] and wheat [27].

One more study tested biofortified wheat lines at multiple locations in South Asia and revealed high heritability and high genetic correlation between locations for grain Zn, suggesting that G × E may not be a serious issue in breeding high Zn wheat genotypes [30, 31].
For breeders, stability of micronutrients is important in terms of changing ranks of genotypes across environments and affects selection efficiency [10]. A genotype is therefore considered to be stable if its contribution to the G × E interaction is low. Several stability measures including univariate and multivariate ones have been developed to assess the stability and adaptability of varieties. The most widely used is the joint regression including regression coefficient (b_i) [9] and variance of deviations from regression (S^2_{di}) [8].
Thus, in present investigation, 50 bread wheat genotypes developed by CIMMYT, Mexico were used to evaluate their stability in plant height, days to heading, 1000-grain weight, grain Zinc and Iron concentrations and grain yield across four environments in NWPZ (Northern Western Plains Zone).

MATERIAL AND METHODS

Plant material

Fifty lines of bread wheat (*Triticum aestivum* var. aestivum) including one check cultivar PBW 725 (401) were grown at four sites in NWPZ (Ludhiana-I, Ludhiana-II, Bathinda, Gurdaspur) during 2016-17 crop season. Each line was sown in two replicate plots of 5 metre long with six rows spaced at a distance of 20 cm. Recommended package of practices was followed to raise a good crop. Observations were recorded on plant height (cm), days to heading (days), 1000-grain weight (gm), grain yield (kg/plot), grain Zn concentration (ppm) and grain Fe concentration (ppm).

Grain analysis

The concentration of elements Fe and Zn in wheat grains was determined using a bench-top, non-destructive, energy-dispersive X-ray fluorescence spectrometry (EDXRF) instrument (model X-Supreme 8000, Oxford Instruments plc, Abingdon, UK), previously standardized for high throughput screening of Zn and Fe in whole wheat grain [25].

Statistical analysis:

Combined analysis of variance on data from trials in three environments was computed according to the method given by Comstock and Moll [7]. Two stability parameters were applied to assess stability performance of genotypes and to identify superior genotypes; b_i, the linear regression of the phenotypic values on environmental index [9] and S^2_{di}, the deviation mean square from regression [8]. Analysis was performed using the statistical software OPSTAT for ANOVA and for stability statistics. To predict stability, a genotype was considered stable for grain Zn and Fe concentrations if it appeared stable in two stability analysis. Genotypes that proved to be stable for both stability parametres were then selected as the best.

RESULTS AND DISCUSSION

This study aimed to define environmental adaptation and stability features and the relationships between stability parameters using 50 bread wheat genotypes that were grown in the ecological conditions of four locations of NWPZ.
The combined analysis of variance for plant height, days to heading, 1000-grain weight, grain Zn and Fe concentration and grain yield across environments is given in Table 1. The difference between environments and genotypes and all interactions for most of the traits investigated were statistically significant ($p<0.01$). For all the traits investigated in this study, components of variation due to genotype and G x E interaction were smaller than the component of variation due to environment. These results are similar with the results of earlier studies [10, 20, 26, 27].
Values of the mean, regression coefficient (b_i) and deviation from regression (S^2_{di}) are given in Table 2. The mean values of total 26 genotypes (from 32.9 to 44.0 ppm) for grain Zn concentration had better performance than check PBW 725 (32.7 ppm). Only one genotype had better performance for grain Fe concentration (37.7 ppm) in terms of mean values than check variety (37.5 ppm). For grain yield per plot, nineteen genotypes had better performance (from 3.3 to 3.9 kg) as check (3.2 kg).
In general, genotypes with high yield, regression coefficient (bi) close to 1, and non-significant deviation from the regression line are considered as the most desirable [8, 4, 16]. Value of regression coefficient less than 1 indicates that the genotype can adapt to poor environmental conditions, whereas a *bi* value greater than 1 indicates that the plant can adapt to favourable environmental conditions [33, 1].
The value of b_i of seven genotypes (402, 413, 418, 433, 439, 440, 441) for plant height; four genotypes (421, 428, 434, 435) for days to heading; five genotypes (410, 413, 422, 442, 445) for 1000-grain weight; three genotypes (404, 436, 445) for grain Zn concentration and three genotypes (408, 416, 440) grain Fe

concentration was unit or very near to unit. Thus these genotypes showed a good stability for corresponding traits.

The value of b_i of six genotypes (401, 417, 438, 442, 444, 450) for grain yield per plot were also unit (Figure 1). Based on the methods of Finlay and Wilkinson (1963), these genotypes can adapt well to all environmental conditions even if the conditions improve or worsen. It is further understood that their yields remain stable. Additionally, three genotypes (417, 442, 450) which had better performance than check for yield, also showed b_i as unit indicated that grain yield of these genotypes is expected to increase if the conditions improve and to remain stable if the conditions deteriorate. Some genotypes were able to adapt to favorable conditions, and their yields were stable only under favorable conditions as their b_i values more than unity (b_i>1). Three of these genotypes i.e. (414, 422, 447) were able to adapt well to favorable conditions, and their yields are expected to increase as the conditions improve.

Additionally, genotypes 407, 410 and 411 did not remain stable for grain yield under favorable or unfavorable conditions as their b_i values less than unity (b_i<1). Similarly, six genotypes (408, 432, 433, 435, 437, 448) for grain Zn concentration and seven genotypes (407, 413, 414, 427, 431, 435, 449) for grain Fe concentration had b_i values more than unity (b_i>1) and were able to adapt to favorable conditions. In case of b_i values less than unity (b_i<1), six genotypes (410, 422, 423, 424, 425, 427) for grain Zn concentration and six genotypes (401, 406, 409, 415, 443, 450) for grain Fe concentration included in this category.

S^2_{di} serves as another stability parameter. For stable genotypes, this value should be low and close to zero [2, 3, 16, 8, 32, 14]. In the present study, the thirty three genotypes (from -6.5 to -0.1) for plant height, thirteen genotypes (from -1.0 to 0.0) for days to heading, five genotypes (from -0.6 to 0.0) for 1000-grain weight, ten genotypes (from -2.0 to -0.3) for grain Zn concentration, twenty two genotypes (from -6.9 to 0.0) for grain Fe concentration and twenty one genotypes (0.0) for grain yield had greatest stability according to this criterion all with values less than or equal to zero (Table 2).

Results revealed that high yielding genotypes can also be highly stable. Genotypes 413, 416, 433, 434, 437 and 442 had better performance than check PBW 725 and desired performance for grain yield per plot in term of high mean, b_i unit or near to unit and least deviation from regression (S^2_{di}), indicating the role of linear portion of G x E interaction in the performance of these genotype (Figure 1). Further on basis of broad selection, total thirty seven genotypes showed stability for grain yield on basis of both stability parameters, out of these fifteen genotypes (419, 421, 423, 425, 430, 432, 433, 434, 435, 441, 442, 445, 446, 448, 450) also had high mean grain yield than check PBW 725.

In view of the stability and adaptation parameters values determined in this study, it can be concluded on basis of two stability parameters that adaptation ability of three genotypes (404, 439 and 441) for grain Zn concentration and three genotypes (417, 437 and 446) for grain Fe concentration are relatively higher and they are more stable than the other genotypes. For grain Zn concentration, these three genotypes also had high mean values compared with mean value of check number 401. Genotypes numbers 404, 439 and 441 were stable for both grain Zn concentration and grain yield and from these, genotype 441 also had high mean value for respective traits. Similarly genotype number 446 was stable for both grain Fe concentration and grain yield and high mean value for grain yield. Any genotype which was highly stable for three traits i.e. grain Zn and Fe concentration and grain yield, not found in this study. As compared to genotypes which are stable for grain Zn concentration and Fe concentration, more genotypes showed stability for grain yield over four environments.

Robert and Dennis [28] have explained that the breeder must keep in mind that the evaluation of stability depends on the sets of genotypes and environments studied. In stability analysis, various statistics should be applied to characterize the genotypes for responsiveness to environments as much as possible and to be sure of the G × E interaction effects.

Our results suggest that almost all traits measured, changed substantially with environments (Table 2). Therefore, production of a cultivar with improved grain Zinc and Fe concentrations and grain yield may need a growing environment that favors expression of this genetic potential. This directs to the production of high yielding biofortified grains. Thus, some genotypes were stable for some traits and unstable for another, suggesting that the genetic factors involved in the G x E differed between traits [10, 5, 20, 26]. The cultivation of more unstable cultivars should be recommended only for specific regions where they can attain a high performance with regard to quality traits independent of seasonal effects.

Genotypes selected according to stability of grain micronutrients and grain yield in present study verified the possibility of combining both stable and high performances. Though, breeders must be aware of the difficulties in selection. The important goal for breeders is to find genotypes with stable traits, not only to provide good raw material for end users, but also to provide parents in the future breeding programmes.

The study was aimed at selection of superior, stable genotype for grain micronutrient and yield as donor for trait introgression. PPMI 904, PPMI 903 and PPMI 906 were found to have high mean grain iron and zinc content with moderate stability. Hence these genotypes can be employed for further biofortification programme in pearl millet.

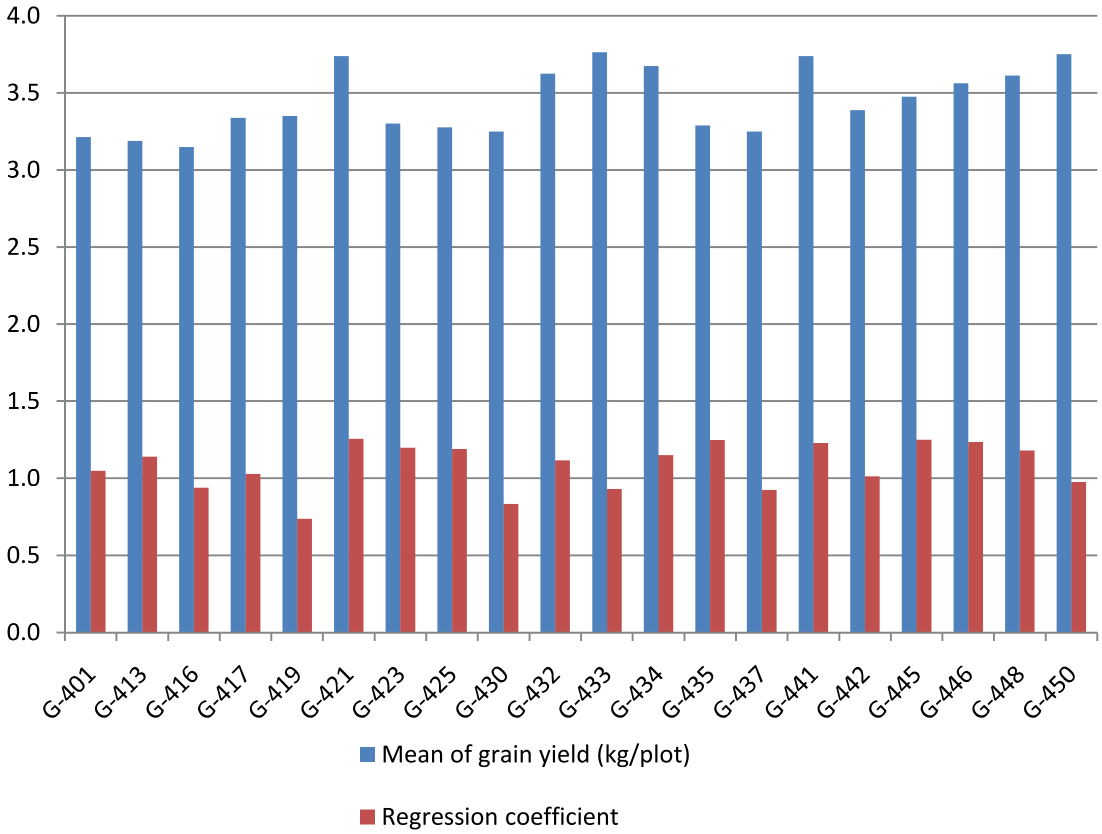

Figure 1. The relationship between the mean grain yield (kg/plot) and regression coefficients for high yielding stable wheat genotypes. (Letter G indicate genotype number of wheat)

Table 1. Combined Analysis of Variance for Stability (Eberhert and Russel Model) of 50 genotypes across four environments

Source of variation	d.f.	M S					
		Plant Height	Days to heading	Thousand grain weight	Zn	Fe	GY
Variety	49	33.092**	39.478**	9.356*	65.739**	16.152	0.361**
Environment	3	559.385**	965.381**	706.575**	235.11**	68.85**	16.764**
Var. X Envion.	147	15.778	7.498**	6.417**	20.775**	11.75	0.133**
Env+Var X Env	150	26.65	26.655	20.42	25.062	12.892	0.465
Env (Linear)	1	1,678.15**	2,896.14**	2,119.72**	705.329**	206.551**	50.292**
Env X Var(Lin)	49	16.022	12.226**	6.671	21.861	12.609	0.086
Pooled Deviation	100	15.343**	5.031**	6.164**	19.828**	11.095**	0.153**
Pooled Error	196	12.994	2.135	1.752	4.102	14.446	0.046

Figures with * and ** are significant at 5% and 1% level of significant, respectively

PH- Plant height, DTH -days to heading, TGW- 1000-grain weight, Zn -grain Zinc concentration, Fe- grain Iron concentration and GY-grain yield

Table 2. Mean (M), regression coefficient (b_i) and deviation from regression (S^2_{di}) for plant height (PH), days to heading (DTH), 1000-grain weight (TGW), grain Zinc concentration (Zn), grain Iron concentration (Fe) and grain yield (GY) for each genotype (G) tested over three environments

G	PH			DTH			TGW			Zn			Fe			GY		
	M	b_i	S^2_{di}	M	b_i	S^2_{di}	M	b_i	S^2_{di}	M	b_i	S^2_{di}	M	b_i	S^2_{di}	M	b_i	S^2_{di}
401	98	0.9	9.4	94	0.8	5.9	42.5	0.5	2.3	32.7	0.7	7.3	37.5	-1.3	1.6	3.2	1.0	0.0
402	99	1.0	-6.4	85	1.9	13.0	38.1	1.3	33.0	33.5	2.1	20.4	32.7	0.8	18.1	3.1	1.1	0.0
403	93	1.9	-5.6	95	0.4	12.6	40.8	0.9	-0.2	32.2	1.8	-0.6	33.2	1.6	-6.0	3.0	1.1	0.0
404	99	0.9	-1.3	84	2.3	0.1	40.1	1.1	5.1	33.8	1.1	-1.7	37.1	-0.3	7.0	2.6	0.7	0.3
405	94	1.6	-2.4	90	1.4	1.6	39.4	1.4	-0.6	31.0	1.7	61.7	35.0	0.2	23.8	3.1	0.9	0.0
406	100	0.9	5.6	96	-0.2	5.6	41.5	1.2	12.4	30.9	0.2	16.2	37.7	-1.3	9.0	3.0	0.5	0.1
407	96	0.9	36.9	92	1.2	2.0	40.9	1.6	12.5	35.5	2.0	-0.3	34.3	3.0	-6.9	2.8	0.4	0.1
408	97	1.1	-3.6	92	1.4	3.9	40.6	1.4	3.4	32.3	2.9	10.4	33.5	1.0	16.7	2.9	0.6	0.2
409	88	1.4	-5.8	91	1.5	7.9	40.1	0.9	3.7	28.6	0.4	47.0	33.4	-1.1	-0.7	3.1	1.1	0.0
410	99	1.5	-2.5	95	0.9	8.8	41.1	1.0	2.8	29.2	-0.4	71.1	34.3	-0.5	-6.9	2.8	0.4	0.4
411	96	1.7	-1.8	93	1.6	-0.4	40.6	1.4	13.8	39.1	1.8	1.4	35.1	-0.5	-5.6	3.1	0.4	0.1
412	98	1.4	8.0	92	1.7	41.4	37.9	0.8	5.2	32.0	0.4	32.9	32.0	-0.3	28.5	2.8	1.2	0.3
413	98	1.0	-5.8	86	1.9	-0.4	41.8	1.0	6.9	30.5	1.9	4.1	30.7	5.4	-0.9	3.2	1.1	0.0
414	92	-1.9	434.0	90	1.6	-0.8	39.6	0.7	8.0	30.2	1.7	11.5	29.0	3.8	12.9	3.5	1.6	0.7
415	103	0.9	-1.6	95	0.9	-0.6	43.1	1.2	25.0	39.0	0.6	-0.6	32.2	-1.7	9.4	3.1	1.2	0.2
416	96	1.7	-4.6	88	0.8	1.4	41.5	1.2	2.8	30.3	2.3	-2.0	30.3	1.0	6.1	3.2	0.9	0.0
417	97	1.5	1.8	92	1.2	1.3	41.6	0.7	4.2	31.6	2.0	8.9	32.2	1.2	-5.2	3.3	1.0	0.9
418	96	1.0	-4.8	92	1.1	1.9	43.8	1.1	1.5	33.6	0.8	1.4	33.9	2.7	6.2	3.0	0.8	0.1
419	95	1.7	-5.8	91	0.8	0.1	43.0	1.2	4.9	40.2	0.7	11.3	29.6	1.8	6.4	3.4	0.7	0.1
420	100	0.8	-3.9	92	1.1	6.4	42.4	0.8	1.3	32.2	0.5	7.1	32.8	1.9	26.8	3.2	1.4	0.0
421	100	0.9	-4.5	92	1.0	1.6	41.0	0.6	3.8	30.1	1.5	9.7	33.1	-0.6	-0.5	3.7	1.3	0.0
422	98	1.4	-6.4	94	0.7	9.9	39.9	1.0	6.1	26.9	-1.6	12.8	31.7	1.4	-6.4	3.1	1.7	0.1
423	98	1.5	-6.5	92	0.7	-0.1	41.6	1.2	0.6	31.5	-1.2	-0.8	31.9	0.0	-0.7	3.3	1.2	0.1
424	93	2.0	13.1	96	0.4	0.0	39.3	1.6	7.0	32.6	-0.2	50.6	30.5	2.1	7.0	3.0	0.7	0.1
425	92	0.0	2.3	96	0.4	-0.1	41.0	1.3	1.8	35.7	-2.5	39.4	35.1	-0.1	3.8	3.3	1.2	0.2
426	96	0.3	-4.2	95	1.1	0.2	38.0	1.4	16.3	44.0	0.4	1.4	32.4	-0.5	2.3	2.9	1.3	0.1
427	97	1.3	-6.2	93	0.8	1.5	41.6	1.4	2.3	39.5	-0.8	28.9	34.3	3.4	1.2	2.9	1.1	0.0
428	92	0.9	-3.7	90	1.0	3.3	40.5	0.8	0.6	30.2	2.3	8.1	33.0	-0.3	21.2	3.0	0.9	0.2
429	98	1.7	2.1	97	0.9	0.3	38.8	0.0	1.2	33.2	1.7	20.6	32.9	1.9	-2.2	2.9	0.6	0.5
430	97	1.3	-5.5	90	1.1	2.7	39.1	0.9	2.0	31.3	0.6	1.3	29.9	-0.3	-1.1	3.3	0.8	0.1
431	92	1.3	-5.7	99	0.6	23.6	38.4	-0.1	4.2	28.1	0.8	0.5	35.6	6.4	-4.5	3.1	0.7	0.2
432	91	1.5	13.6	89	0.5	3.7	40.4	1.2	5.5	37.1	3.0	3.7	30.5	2.2	10.1	3.6	1.1	0.1
000433	94	1.0	-4.5	91	0.9	8.5	41.5	0.9	10.5	29.3	3.4	29.3	31.5	2.0	-5.2	3.8	0.9	0.0
434	97	0.7	2.6	92	1.0	3.1	40.9	1.1	-0.1	34.2	0.4	-0.5	31.3	1.9	0.3	3.7	1.1	0.0
435	97	-0.3	-3.4	91	1.0	3.8	38.8	1.3	1.1	33.2	2.4	2.8	30.6	3.2	-1.9	3.3	1.2	0.2
436	97	1.4	-5.0	93	0.9	-0.9	39.3	1.1	2.9	34.6	1.1	43.1	31.0	2.3	5.2	2.9	0.7	0.2
437	96	-0.1	8.0	92	0.9	-1.0	38.6	0.9	3.6	34.0	3.6	3.5	33.5	0.8	0.0	3.3	0.9	0.0
438	101	1.7	18.8	92	0.9	4.4	41.0	1.4	5.1	43.6	-0.1	13.5	34.4	0.0	1.1	3.0	1.0	0.0
439	95	1.0	1.1	94	1.3	0.0	36.9	0.1	10.0	38.3	0.8	-0.7	28.8	1.7	-5.8	3.1	1.1	0.0
440	99	1.0	-0.8	92	0.9	5.4	41.0	1.5	1.5	32.9	0.8	19.3	31.7	1.1	5.4	3.0	1.1	0.0
441	97	1.0	-0.5	93	0.8	-0.1	42.4	0.7	0.4	38.3	1.3	-1.5	32.3	-0.9	-5.2	3.7	1.2	0.1
442	102	0.4	-6.1	94	0.9	-0.2	41.1	1.0	1.9	34.2	0.0	-0.9	32.6	0.1	3.6	3.4	1.0	0.0
443	99	0.6	-5.4	96	0.9	0.8	38.8	0.4	3.6	40.9	0.3	5.5	35.5	-1.2	32.8	3.2	0.7	0.1
444	98	0.7	-3.6	95	0.7	3.5	38.3	1.4	9.8	34.5	0.0	0.7	32.6	0.0	3.1	3.1	1.0	0.0
445	99	0.3	4.8	99	0.4	6.2	40.9	1.0	1.5	40.8	1.1	4.4	34.1	-0.3	-4.9	3.5	1.3	0.3
446	98	0.8	-1.4	94	1.1	-0.1	40.3	1.1	-0.2	36.0	2.1	19.4	33.2	1.2	-2.2	3.6	1.2	0.0
447	98	-0.3	-2.9	96	0.6	0.6	37.9	0.3	0.0	30.7	0.0	60.6	33.9	2.2	0.4	3.9	1.5	0.3
448	97	0.9	9.0	90	1.1	0.3	39.9	1.2	4.2	34.5	2.5	5.8	32.3	1.6	-6.7	3.6	1.2	0.0
449	95	1.8	-0.1	97	0.4	3.0	41.3	1.4	5.8	28.8	1.5	162.1	32.1	3.0	-0.7	3.0	0.8	0.0
450	95	1.3	3.2	87	1.6	2.6	40.8	0.6	3.4	29.3	-0.1	38.6	32.8	-1.6	3.8	3.8	1.0	0.3

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