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THRESHING METHOD-CAUSED DAMAGE TO SEEDS OF MAIZE AND VARIATION OF THE SEEDS' SUSCEPTIBILITY TO (Sitophilus zeamais)STORAGE INSECT PEST

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ABSTRACT

Varying damage levels occur in maize during threshing. An experiment was conducted to establish maize threshing-caused damage to kernels and subsequent seeds' susceptibility to storage insects. Kernels threshed by: machine, beating with stick, or pressing with fingers were assessed for broken kernels, physiological performance with storage time, and hosting of Sitophilus zeamais storage pest. Mechanical threshing or beating with stick both caused kernel breakage. Beating with stick caused less damage than mechanized threshing in number of broken kernel pieces and broken whole kernels ($P<0.01$). Seeds stored for two months and beyonds' germination capacities were lower ($P<0.05$) in machine-threshed than in seeds threshed by fingers. The physiological influence during storage was partly due to storage insect pests rather than threshing caused damage alone. After 2 and 3 months, number of S. zeamais in mechanized threshing was statistically larger than in fingers threshed grains. Percent normal seedlings was low in all threshing methods insecticide-untreated samples at two months of storage; significantly lower than percentages for treated samples. Mean germination time was significantly positively correlated with number of broken kernel pieces and the number of storage insect counted in the samples; which means the two kernel damage attributes suppressed seed vigour.

Keywords: Kernel breakage, Physiological performance, Vigour, mechanized shelling, storage insecticide

1. INTRODUCTION

Maize (Zea mays) is a very important crop cultivated worldwide as a source of human food, animal feed and innumerable industrial products. According to Amare et al (2017), the crop is the cheapest source of food and feed starch, and serves as a valuable raw material for production of industrial starch, protein, oil, alcoholic beverages, food sweeteners, and more recently, fuel. Vishwanatha (2005) reports that maize is estimated to yield about 4,000 industrial products and that in USA supermarkets there are more than 1,000 items that contain maize. Among the industrial products include gluten (protein) for animal feed, syrup, dextrose used in pharmaceutical industry, fructose corn syrup used in soft drinks, ethanol fuel, biodegradable chemicals and plastics, rubber, paper, additives in paint and explosives, textiles, etc. (Ibid). The harvested grains of the crop are borne on ears or cobs which have to be threshed with significant use of energy. Kernels of well filled maize cobs are usually very tightly packed and attached firmly to the cob inside a tough husk. Separating the kernels (or grains) from the cob is no easy task, and is what is known as threshing or shelling in maize. Harvesting of maize may be in husks then de-husked later then shelling will follow, or de-husking may be performed while hand harvesting, leaving the husk attached to the remaining straw plant in the field. Combine harvesters, on the other hand, perform instantly the harvesting and next post-harvest processes to have the harvested crop being the kernels. That is, combines picking or stripping, de-husking, threshing and field cleaning.

Threshing or shelling is one of the most labour intensive operations in maize crop production. For this reason it is also one of the operations that attract mechanization the most. Thus there are manual and mechanized methods available for threshing of maize. Vishwanatha (2005) describes manual or traditional maize threshing methods to include pressing on the grains with thumbs (or in other words threshing with bare hand fingers), rubbing two ears of maize with each other, beating of the cobs (usually in a bag) with sticks, threshing with handheld tools (wooden or slotted metal cylinders), and using hand-driven shellers. Amare et al (2017) report other traditional maize shelling methods viz. using pestle and mortar and treading with animals. Mechanized threshing methods, on the other hand, are either of two categories: separate shelling using fuel or electricity or PTO shaft driven machines; or combining harvesting, shelling and field cleaning using maize combine harvesters. In all threshing methods, the process is reported to be achieved either by rubbing, stripping or impact action or using a combination of these actions (Kumar and Kalita (2017). Manual threshing is claimed to be predominating threshing in developing countries. Indeed in Tanzania, and likely most of Africa, it is.

Significant grain and seed quality loss is incurred during harvest and post-harvest crop production operations. According to Gustavson et al (2011), every year approximately one third of food produced globally is lost during post-harvest operations. Zorya et al (2011) point out that every year, also, sub-Saharan Africa alone loses about 4 billion USD worth of food grains. In severe cases it is argued that post-harvest losses are up to 80% of the total production (Fox, 2013). Among these loses are those incited by threshing activities. Spillage, incomplete separation of grain from the chaff, and grain breakage due to excessive striking are some of the reasons for losses during threshing (Kumar and Kalita, 2017). Grain damage, particularly, present a very significant and sometimes visually invisible cause of loss. Al-Jalil (1978) report about 16.4 – 79.4% of kernels having been damaged in a typical combine harvesting system. Injuries on kernels during harvesting and subsequent or accompanying post-harvest operations may range from breakage and bruising to cracks and internal physiological damage (Ajayi et al, 2006; Gu Ri-liang et al, 2018).

Implications of grain damage may be far reaching. Broken pieces of grain can be lost directly during the grain handling. Al-Jalil (1978) reports that average quantity of screenings, largely cracked corn and kernel tips, that are cleaned out before grain gets to the consumer is over 3%. Uhrig (1968) argue that the screenings are often higher in protein content and lower in fibre than whole kernels. Most of the kernel tips that are not retained in the grain are in reality left in the threshed cob. Presence of cracked or broken kernels in marketed grain lowers the commercial grade of the grain, especially if it is for export. The East African Grain Council, for example, tolerates only about 2% broken grains for grade 1, 4% for grade 2 and 6% for grade 3 commercial grains (EAC, 2014). Cracked and broken kernels are reported to characteristically tending to accumulate in the center of storage bins, which makes aeration difficult and increase probability of heating and spoilage (Dodds, 1972; Bailey, 1968). Cracked kernels are also reported to be good carriers of dust and microbial contamination (Gustoff, 1971), the dust representing loss of grain quality and may be a significant cause of pollution problems including fungal spores alongside the dust that may be sources of human respiratory allergies (Al-Jalil, 1978). Generally, damages on grains predispose the grains to invasion by insect pests, moulds and fungi. Then those invaders will cause a series of serious further damages. Insects shorten storage life of grains as they feed on valuable content of the grain and if not controlled they completely destroy the grains. Various authors have reported average grain losses due to insect pests during storage to range from 30 – 40 % (Abass et al, 2014; Boxall, 2002; Tapondjou et al, 2002). Increased development of moulds and fungi especially in field shelled (combine harvester) maize when moisture content of the grains is likely to be high prompts the necessity for immediate drying of the grains after harvest. Enhanced development of moulds and fungi increase the risks of grain discolouration and in severe situations even decays, but also increase production of mycotoxins that harm human and livestock health when such grain is consumed.

A very important consequence of grain damage even when such damage is not evident from the external visual observation is incitation of physiological deterioration of the grains when the crop production is a seed crop. Gomez and Andrews (1971) observed drastically reduced viability and vigour in maize seeds that were mechanically injured. Souza and Marcos-Filho (2001) likewise, remarked that seed with damaged seed coat usually had lower viability and vigour. Phillips (2010) also report observation that excessively damaged seeds were unable to germinate, as also reported by other workers (Spokas et al., 2008; Gu Ri-liang et al, 2013; Masilamani et al, 2017).

Various grain threshing methods variably subject the grains to damages and subsequently loss of value and quality of the grains and seeds. Least damage, loss and deterioration are generally achieved when threshing is gentliest. Pandey et al (2013), for example, found more embryo damage in maize seeds shelled by machine against shelling by hand, and consequently germination of machine shelled grains was reduced while it was higher in hand shelled grains. Testing different varieties of maize, Gu Ri-liang et al found that damage percentages caused by mechanical threshing were 21.5% in one variety and 10% in another variety; values that were 2 – 3 fold higher than those by manual threshing. In rice, Govindaraj et al (2017) found maximum vigour index in seeds harvested and threshed manually.

In Tanzania, most of maize produced is still threshed manually predominantly by beating with stick. This is a very labour intensive activity. A mechanized alternative that has been in existence for a longer time has been the use of tractor operated maize shellers. Such machines, however, have been of extremely limited availability especially in rural areas, and even where they could be used many farmers may opt for manual threshing to avoid extra costs of hiring the threshing service. Recently, self propelled liquid fuel driven maize threshing machines that are small enough in size and easily portable have begun to appear in the market. Such machine seems to be appropriate technology for many farmers use. While using this type of machine to thresh maize crop of the 2017 harvest, interest was developed to investigate whether the labour and time saving machine could at the same time be advantageous in terms of grain damage and subsequent susceptibility of the threshed grains to storage insect pests.

2.MATERIALS AND METHODS

Experiment particulars and description of treatments

The research was conducted from September 2017 to January 2018 in Morogoro, Tanzania, after the 2017 crop harvest season. Maize was harvested manually in August then the cobs dried in a wooden platform well ventilated from bottom and sides for about a month. Threshing was performed in September, therefore the threshing experiment commenced then. While the crop was being threshed by a machine (self propelled, liquid fuel driven), a sample of cobs was taken and threshed by hand using bare fingers. Another sample was threshed by beating the cobs with stick in tightly packed gunny (sisal) sack. A sample was drawn from the bulk of the machine and manual-threshed grains for the comparative study of threshing method impact on grains.

Data collection plan and implementation

Assessment of grain damage was performed by counting numbers of broken pieces in each threshing method sample; and the number of broken whole kernels. Broken pieces were described as any broken piece regardless of size but including "whole grains" with clearly visible white endospermic inner part of the grain and the outer seed cover because of some broken missing small portion of the grain. Broken whole grains were described as whole grain with broken part exposing white endospermic matter but still retaining morphological predictable features. In this context half or close to half grain or grain whose embryo is removed was not considered in the category of broken whole grain. Four replicates of each threshing method sample were used, whereupon each replicate was one kg weight of the threshed grains. Resources were not available (Iodine blue, Fast green, Electrolyte leakage (conductivity) test, X-ray radiography, etc) to test for cracks in unbroken kernels, which is another indication of damage. Alternatively, physiological tests in form of germination and vigour were performed; as well as potential susceptibility to insect pest attack. The collected seed samples after threshing were held in polyethylene bags for about three weeks then germination and vigour assessment was performed. Before each germination test, the number of Sitophilus zeamais insect pest, which is the predominant storage insect pest in maize in Morogoro, was counted. The germination alongside vigour assessment was performed by sowing unbroken kernels in a bowl filled with sand as germination medium. Number of seeds germinated was counted to the 10th day after the beginning of the germination experiment. To obtain data on vigour, number of seeds that germinated was counted everyday to 5th day, then after 7 and 10 days. Data on vigour would then be computed as MGT (mean germination time), which is a description of speed of germination presented as number of days the seeds reach median of the maximum germination achieved for a test sample. Vigorous seeds reach the median earlier. Slow germinating seeds for a crop species indicate low vigour. Germination was expressed as percent number of the sown seeds that germinated for each sample. Data on vigour were also collected in terms of normal and abnormal seedlings resulting from the germination test. Each of the threshing method sample of seed was kept under room conditions and germination tests and insect counts performed on monthly basis.

A RCBD (Randomized complete block design) was used as an experimental procedure to enable analyzing differences in threshing method treatments. To implicate storage insect pests with value of the threshed seeds, separated samples for each threshing treatment were treated with storage pest insecticide and kept in the same way as untreated samples for monthly data collection. Thus while treatments at the beginning of the experiment were: Hand threshing with fingers; Manual beating with stick; and Machine harvesting; after inclusion of insecticide dressing treatments involved also treated samples for each threshing method.

3.DATA ANALYSIS

Data collected were subjected to analysis of variance and mean separation to reveal significant treatment effects. Correlation analysis was also performed to establish association between tested parameters

4.RESULTS AND DISCUSSION

Indication of kernel damage as a result of threshing method is presented in Table 1 which shows that significant kernel breakage is accompanied with machine threshing as well as threshing by beating the maize cobs with sticks. No kernel breakage was observed when shelling was gentliest using fingers. Beating with sticks caused less damage which was significantly different from mechanized threshing in terms of both the number of broken pieces and the number of broken whole kernels ($P < 0.01$). In terms of broken whole kernels, however, beating with sticks was not significantly different from hand shelling with fingers. Initial germination capacity and accompanied speed of germination (MGT) showed absence of any significant impact of the threshing methods to those physiological attributes of seed. Such likely impact was shown only after a period of storage of the seeds. This appears in Table 2, where significant influence of threshing method on germination of the seeds during storage is presented. From the Table, when seeds had been stored for 2 months and beyond there was significant differences ($P < 0.05$) in germination capacity between the threshing methods. After 2 months of storage early (72 hours) as well as maximum (10 days) germination percentages were significantly lower in machine threshed crop than in hand fingers threshed grains. After 3 months of storage, mechanized shelling caused significantly lower germination of seeds than shelling by stick. The data may be suggesting that when seeds are damaged whether externally (cracks) or internally, there may be a delay in physiological expression of the damage until after a period of storage. This physiological influence, additionally, seems to be accompanied with attributes other than the threshing caused damage alone. In the same Table 2, influence of storage insect pest association with the physiological expression is apparent. One month of storage early (72 hrs) germination percentage, for example, showed significant variation between the samples tested, but this difference was obviously a result of insect pests rather than direct effect of threshing. The significant ($P < 0.05$) difference observed was a result of insecticide dressing of the seeds, which eliminates storage insect infestation. Germination percentage of the differently threshed seeds but not treated with insecticide was statistically the same. Likewise germination percentage of insecticide treated seeds was statistically the same amongst threshing methods. Stick threshed untreated seeds were significantly lower in early germination than untreated seeds regardless of threshing method. All the threshing methods untreated seeds early germination, at the same time, was significantly lower than germination of seeds threshed with fingers and treated with insecticide. Obviously, exclusion of insects was responsible for higher germination which is evidence of insects involvement in reducing germination, and involvement of the insects has been shown to be greater in the threshing damaged seeds that is why machine and stick threshed treated seeds were not significantly better than the untreated seeds. That grain damage predisposed insect pest susceptibility of the grains has therefore also been evidenced, as it has also been claimed by various authorities (Amare et al, 2017; Wikipedia, n.d.; Al-Jalil, 1978). Two months of storage mechanized and stick threshed untreated seeds were significantly lower in germination than all of the treated seeds regardless of threshing method. But when threshing was with fingers there was statistical similarity ($P < 0.05$) with some of the treated seeds, even when the hand fingers threshed seeds were not insecticide treated. This is another evidence of grain damage predisposition of insect pest damage. Three months of storage, germination of the insecticide untreated seeds was already very low and these seeds were already almost totally valueless whether as seeds or grains.

Table 3 shows Sitophilus insect pest counts from the variably threshed seeds. At the beginning of the experiment and one month of the grains storage there was no significant difference in number of insects counted between the threshing methods. After two and three months of storage, the differences were significant, whereby the number of the insect in mechanized threshed grains was statistically larger ($P < 0.05$) than the number in hand fingers and stick threshed grains. With greater number of the insect counted in the machine as well as beating with stick threshed grains as compared to threshing with fingers, implication of this is that mechanical damage on the grains encouraged more insects attack and reproduction in the grains.

Table 1. Grain breakage and initial germination of maize seeds threshed by three different methods

Threshing method	Number of broken kernel pieces	Number of broken whole kernels	Germination % after 48 hours incubation	Germination % after 72 hours incubation	Germination % after incubation for 10 days	MGT (days)
Mechanized	86.2	15.5	10.9	76.6	85.85	3.08
Stick	29.2	3.8	10.8	73.3	92.52	3.13
Fingers	0	0	6.7	74.1	91.05	3.16
Mean	38.5	6.4	9.5	74.7	93.34	3.12
S.E.	11.65	4.03	3.81	12.04	3.1	0.16
CV	30.3	62.8	40.3	16.1	3.3	5.2
Probability	<.001	0.004	0.278	0.922	0.209	0.790

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$LSD_{0.05}$	20.15	6.97	ns	ns	ns	ns

Table 2. Germination capacity of machine, stick and fingers-threshed seeds during different periods of the seeds storage under influence of Sitophilus zeamais storage insect pest

Threshing method	Germination % after 1 month		Germination % after 2 months		Germination % after 3 months	
	72hrs incubation	10 days incubation	72hrs incubation	10 days incubation	72hrs incubation	10 days incubation
Mechanized	79.2	84.2	32.5	36.7	1.1	0.83
Stick	73.3	79.2	49.2	55.8	6.67	9.15
Fingers	80	90.8	58.3	65	4.42	4.98
Mechanized_Treated	90	87.8	81.1	92.2	79.97	84.43
Stick_Treated	91.1	94.4	75.6	84.4	78.88	87.8
Fingers_Treated	94.5	95.6	86.7	93.3	91.1	98.9
Mean	84.7	88.7	63.9	71.2	43.69	47.68
S.E. ±	8.61	8.77	16.68	16.21	4.48	3.9
CV (%)	10.2	9.9	26.1	22.8	10.3	8.2
Probability	0.021	0.130	0.002	<.001	<.001	<.001
$LSD_{0.05}$	12.98	ns	25.13	24.44	6.75	5.88

Table 3. Interval counts of Sitophilus zeamais insect pest in variously threshed and stored maize kernels

Threshing method	Initial count	Count after 1 month	Count after 2 months	Counts after 3 months
Mechanized	29	151	552	803
Stick	21.8	114	318	458
Fingers	33.2	84	317	411
Mean	28	116.3	396	557
S.E. +	18.61	43.6	114.8	118.9
CV (%)	66.5	37.5	29	21.3
Probability	0.693	0.176	0.043	0.007
$LSD_{0.05}$	ns	ns	198.7	205.7

Vigour of seeds in relation with threshing damage of the seeds, expressed as percent normal seedlings and MGT, is presented in Table 4. Both vigour attributes showed significant response to threshing method and its effects. In one month stored seeds percent normal seedlings after the germination test for mechanized threshing was significantly less than normal seedlings from seeds threshed using fingers. This was so for both insecticide treated and untreated seeds. Treated and untreated seeds' normal seedlings in respectively mechanized and finger threshed grains were statistically the same ($P < 0.05$). This indicates direct effect of the threshing method damage on the vigour parameter. Stick threshed untreated seeds percent normal seedlings was in the contrary significantly different from its stick threshed treated seeds counterpart, which directly shows influence of insects to reduce seed vigour in the untreated seeds. The influence of threshing damage alone on the vigour parameter in the insecticide treated seeds was not significant between stick threshed and fingers threshed samples. So we can say that the effect of threshing damage on percent normal seedlings in the untreated samples was significant only because of presence of an additional impact of the storage insects. Two months of storage, percent normal seedlings was low in all untreated threshing method samples, and all the untreated seed percentages were significantly lower than percentages for treated samples. This obviously shows almost sole influence of storage insects at this stage. As regards MGT, one month of storage finger threshed and insecticide treated seeds were significantly quicker in germination (higher vigour) than machine threshed untreated seeds. Two months of storage, however, no significant difference in MGT was observed. It seems that percent normal seedlings is a more sensitive measure of seed vigour physiological expression than the speed of germination, particularly as regards kernels internal or invisible damage.

Table 4. Percent normal seedlings and speed of germination (MGT) of variously threshed seeds after periods of storage

Treatment	After one month of storage		After 2 months of storage	
	Normal seedlings	MGT	Normal seedlings	MGT
Mechanized	63.4	3.045	27.5	3.022
Stick	66.7	3	44.2	3.08
Fingers	80	2.862	47.5	3.1
Mechanized_Treated	73.4	2.862	84.4	3.107
Stick_Treated	81.1	2.86	78.8	3.08
Fingers_Treated	93.4	2.6	87.7	2.99
Mean	76.3	2.872	61.7	3.063
S.E. ±	8.97	0.1785	17.55	0.18
CV (%)	11.8	6.2	28.4	5.9
Probability	0.003	0.044	<.001	0.924
$LSD_{0.05}$	13.52	0.269	26.44	ns

Table 5 shows correlations of some of the damage attributes and measurements of the variably threshed grains. Several sensible significant correlations were noted. Grain damage in terms of kernel broken pieces was, for example, significantly positively correlated with the storage insect counts throughout the storage period. It was also significantly positively correlated with percent abnormal seedlings and was significantly negatively correlated with percent normal seedlings. Significant correlation with broken whole kernels was less frequent than with number of broken pieces; but it was highly significant with percent abnormal seedlings after one month of storage (r = 0.7498**) and insect counts after 3 months of storage (r = 0.7935**). From the data, increasing number of broken kernel pieces also increased MGT thus delayed germination in one month stored seeds (r = 0.5564*), and reduced germination (significantly) in 2 months stored seeds (r = -0.6236*). Insect counts one month of storage significantly reduced germination of seeds one month (r = -0.5426*) and subsequently two months (r = -0.8484**) and three months (r = -0.6872*) of storage. It also was associated with significant delay of germination (increased MGT) at one month of storage (r = 0.5066*). We can conclusively say that from the correlation statistics, increased kernel damage increased insect activity (numbers or in other words reproduction) in the seeds; and that both increased damage and increased insect activity reduced germination and vigour of the seeds. Other significant associations are as it is indicated in the Table.

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Table 5. Correlation between and among various grain damage and physiological performance parameter of variously threshed maize kernels

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Broken pcs	1	-																
Broken whl	2	0.915**	-															
Ct Initial	3	-0.138	-0.105	-														
Gnn_Intl	4	0.614*	0.562*	0.115	-													
MGT_Intl	5	-0.314	-0.322	-0.188	-0.268	-												
Ct_1month	6	0.634*	0.360	-0.047	0.446	-0.154	-											
Gnn_1month	7	-0.157	0.014	-0.358	0.053	0.218	-0.543*	-										
Im abnormal	8	0.695*	0.750**	-0.017	0.238	-0.591*	0.373	-0.039	-									
1m normal	9	-0.502*	-0.392	-0.287	-0.085	0.496	-0.645*	0.843**	-0.570*	-								
1m_MGT	10	0.556*	0.407	0.140	0.203	-0.666*	0.507*	-0.411	0.714**	-0.721**	-							
Ct 2months	11	0.659*	0.519*	0.247	0.385	-0.003	0.582*	-0.407	0.187	-0.434	0.202	-						
Gnn 2months	12	-0.624*	-0.429	-0.015	-0.458	0.404	-0.848**	0.576*	-0.402	0.688*	-0.434	-0.517*	-					
2m abnormal	13	-0.438	-0.065	0.016	-0.155	-0.047	-0.722**	0.399	-0.118	0.388	-0.419	-0.545*	0.509*	-				
2m norrmal	14	-0.508*	-0.405	-0.046	-0.478	0.487	-0.692*	0.517*	-0.333	0.604*	-0.315	-0.42	0.944**	0.226	-			
2m MGT	15	-0.076	-0.129	-0.114	0.129	-0.360	0.276	-0.323	-0.146	-0.185	-0.012	0.125	-0.414	0.086	-0.593*	-		
Ct 3months	16	0.923**	0.794**	-0.033	0.401	-0.242	0.593*	-0.270	0.588*	-0.536*	0.550*	0.820**	-0.551*	-0.572*	-0.403	-0.065	-	
Gnn 3months	17	-0.441	-0.349	-0.083	-0.359	-0.066	-0.687*	0.119	-0.398	0.3114	-0.056	-0.476	0.579*	0.452	0.454	-0.032	-0.378	-

Number of observations = 12 * Significant at 0.05 ** Significant at 0.01

Correlation parameters: 1: Number of broken kernel pieces 2: Number of broken whole kernels 3: Initial insect count 4: Initial germination 5: Initial MGT

6: Insect count after 1 month 7: Germination after 1 month of storage 8: % Abnormal seedlings 1 month 9: % Normal seedlings 1 month 10: MGT 1 month, etc

6.CONCLUSION

Results of this study have shown that both mechanized threshing and beating with sticks cause significant damage to grains and seeds. It is likely that whatever threshing method if it is based on high output and time saving it will cause considerable damage to the kernels. It has been shown that mechanized threshing caused more damage both visible instantly (kernel breakages) and invisible (seed germination, vigour and hosting of storage insect pests). It has also been shown that the more the kernel visible damage the more the insect pest infestation during storage and consequently less physiological performance of seeds in terms of germination capacity and vigour. It cannot however be recommended to advocate hand (fingers) threshing which is gentliest except in occasions of very small quantities of very valuable grains such as nucleus seed, valuable germplasm or gene bank seed. But it is recommended that development of mechanized threshing must strive to install mechanisms that minimize impacts and injuries on grains as much as possible.

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