International Journal of Advanced Research in Social Sciences, Environmental Studies & Technology
p-ISSN: 2536-6505 | e-ISSN: 2536-6513
Volume 10, Number 1 July 2026
IJARSSEST

Effects of Varieties and Intra-Row Spacings on Growth, Yield and Yield Components of Sorghum (*Sorghum Bicolor* (L.) Moench) in Adamawa State, Northeastern Nigeria

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Article DOI: 10.48028/iiprds/ijarssest.v10.i1.08

Abstract

A field experiment was conducted during the 2025 rainy season at Yola and Ganye, Adamawa State, Northeastern Nigeria, to evaluate the effects of variety and intra-row spacing on growth yield and yield components of sorghum. Four varieties (Jigari, Kaura, SC-XP104, and Samsorg 53) and three intra-row spacings (75 x 25, 75 x 35, and 75 x 45 cm) were tested in a split-plot design with three replications. Data were collected on grain yield per panicle, per plot, per hectare, and 1000-seed weight. Samsorg 53 gave the highest grain yield per hectare (8308.0-8723.3 kg/ha) and Jigari the lowest (1774.6-1862.8 kg/ha). Closer spacing raised yield per hectare, while wider spacing improved per-plant yield components; Ganye outperformed Yola. Variety by spacing interactions were significant for all traits, indicating genotype-dependent optimal spacing. Samsorg 53 at 75 x 25 cm spacing is recommended for maximum grain yield under rainfed conditions in Adamawa State.

Keywords: *Sorghum bicolor, Intra-row spacing, Grain yield, 1000-seed weight, Split-plot design, Adamawa State*

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Background to the Study

Sorghum (Sorghum bicolor (L.) Moench) is the fifth most important world cereal crop after maize, wheat, rice, and barley (FAO, 2019). It is a staple food crop in the drier parts of Africa, China, and India (Ajeigbe, Akinseye, Jonah, & Kunihya, 2018; Mrema, Shimelis, & Laing, 2017). The largest world sorghum producers are the USA with total annual grain production of 8.7 million tons from 2.0 million hectares, Nigeria (7.1 million tons from 5.8 million hectares), Ethiopia (5.8 million tons from 1.9 million hectares), and Sudan (3.9 million tons from 6.8 million hectares) (FAO, 2024).

Nigeria is the leading sorghum producer in Africa. Sorghum accounts for about 50% of total cereal output and occupies approximately 45% of the total land area devoted to cereal crops production in Nigeria (FAO, 2019). The sorghum productivity in the country stands at 1.23 t ha^{-1}, which is relatively low compared with the world average of 1.45 t ha^{-1} and the USA average of 4.58 t ha^{-1} (FAO, 2019). Sorghum is relatively tolerant to drought and waterlogging (Curtis, 1967; Mrema et al., 2017) and has a wide adaptation to varied soil conditions (Ajeigbe et al., 2018), making it the staple crop of choice in Africa's driest regions for food and income security.

The low productivity of sorghum in Nigeria (averaging 1.1–1.4 t ha^{-1} on smallholder farms) is substantially below the crop's genetic potential of 2.5–3.5 t ha^{-1} under improved management (Amouzou et al., 2019; Ajeigbe et al., 2018). Among the factors responsible for this yield gap are the use of unimproved varieties, inappropriate plant populations, declining soil fertility, and limited access to production inputs (Sani, Haruna, & Sirajo, 2013). Small-scale farmers, who account for over 90% of sorghum production, continue to use farm-saved seed of local unimproved varieties characterized by low yield potential, long maturity, tall plant height, and non-responsiveness to improved agronomic management (Ajeigbe et al., 2018).

Plant spacing is a fundamental agronomic factor that regulates inter- and intra-specific competition for light, water, and nutrients, thereby determining crop productivity. In sorghum, planting configuration significantly affects plant density, canopy development, and yield components including grain yield per panicle, yield per unit area, and individual grain weight (Houx, Roberts, & Kitchen, 2025; Ogunwole, 2022). Closer spacing increases plant population per unit area, potentially boosting yield per hectare, while wider spacing reduces competition, allowing individual plants to produce larger panicles and heavier grains. The optimal spacing configuration is, however, variety-dependent, as different genotypes exhibit different degrees of phenotypic plasticity in response to population density (Maina, Mbega, & Ndakidemi, 2024).

Despite recognition of the importance of variety-spacing interactions in sorghum, systematic evaluation of these interactions under the specific agroecological conditions of Adamawa State is limited. This study was therefore conducted to evaluate grain yield and yield components of four sorghum varieties under three intra-row spacing regimes, with the specific objectives of: (i) determining the effect of varieties on grain yield per panicle, yield per plot, yield per hectare, and 1000-seed weight; (ii) evaluating the influence of intra-row spacing on these yield parameters; (iii) assessing variety spacing interactions for yield traits; and (iv) identifying the optimal variety– spacing combination for maximizing sorghum yield under rainfed conditions in Adamawa State, Northeastern Nigeria.

Materials and Methods

Experimental Site

The experiments were conducted during the 2025 rainy season at two locations in Adamawa State, Northeastern Nigeria: (i) the Teaching and Research Farm of the Department of Crop Production and Horticulture, Modibbo Adama University, Yola (Latitude 9°35'38"N; Longitude 12°50'45.3"E), and (ii) Adamawa State College of Agricultural Science and Technology, Ganye. Both sites fall within the Sudan Savanna agroecological zone, which is characterized by a monomodal rainfall pattern with annual rainfall of 900–1100 mm (Adebayo and Tukur, 1999). The soils at both sites are light textured, with the site at an altitude of approximately 200 m above sea level.

Planting Materials

Four sorghum varieties were used: (i) Jigari, a tall (60–85 cm), deep-red-grained, earlymaturing (85–95 days) local landrace with semi-compact to compact panicle and yield potential of 2.0–3.1 t ha^{-1};(ii) Kaura, a tall (2.0–2.5 m), cream-white-grained, late-maturing (110–130 days) variety with large open panicle and yield potential of 2.2–3.5 t ha^{-1};(iii) SC-XP104, a white-grained, compact-panicled improved variety (1.0–1.5 m) with late maturity and yield potential of 2.8–4.1 t ha^{-1}; and (iv) Samsorg 53, a medium-maturing (95–100 days) improved variety of medium stature, semicompact elliptic panicle, white grain, and yield potential of 2.5–4.2 t ha^{-1}.Jigari and Kaura are local farmer-preferred cultivars, while SC-XP104 and Samsorg 53 were obtained from Seed Co Nigeria.

Experimental Design and Treatments

The experiment was laid out in a split-plot design with three replications. The main plot factor was variety (Jigari, Kaura, SC-XP104, and Samsorg 53), while the sub-plot factor was intra-row spacing (75 cm×25 cm, 75 cm×35 cm, and 75 cm×45 cm). The gross plot size was 3 m×2 m with 0.5 m between adjacent plots and 1.0 m between replications. Each replication comprised 12 sub-plots (4 main plots×3 spacings), giving a total of 36 plots per location.

Agronomic Practices

The land was cleared of shrubs and stubbles and ploughed. Beds were manually prepared using hoes in accordance with the experimental design to provide sufficient tilth for germination and root development. Fertilizer was applied at 3, 6, and 9 weeks after sowing (WAS). Thinning was carried out at 2 WAS to maintain two plants per stand. Weeding was conducted manually at 3 WAS and 8 WAS.

Data Collection

Five plants were randomly selected, tagged, and sampled from each plot for data collection. The following yield parameters were measured:

i). Grain yield per panicle (kg): panicles from the five sampled plants were individually threshed and weighed after harvest to obtain average grain yield per panicle.
ii). Grain yield per plot (kg): all panicles from the net plot area were harvested, threshed, cleaned, dried, and weighed using a digital balance.
iii). Grain yield per hectare (kg ha^{-1}): calculated by converting yield per plot using the formula: Grain yield (kg ha^{-1})= [Grain weight (kg/plot)×10,000] / Net Plot Area (m^2). (iv) 1000-seed weight (kg): randomly selected 1000 grains from the cleaned grain sample were weighed using a digital balance.

Data Analysis

Data were subjected to analysis of variance (ANOVA) appropriate for a split-plot design using Genstat statistical software. Means were separated using the Least Significant Difference (LSD) test at the 5% probability level where the F-test was significant.

Results and Discussion

Grain Yield Per Panicle (kg)

Grain yield per panicle was highly significantly ($P \leq 0.001$) influenced by variety, spacing, and their interaction at both locations as shown in Table 1. Samsorg 53 produced the highest grain yield per panicle (0.115 kg at Yola; 0.120 kg at Ganye), significantly superior to all other varieties. SC-XP104 ranked second (0.057 kg at Yola; 0.060 kg at Ganye), followed by Kaura (0.047 kg; 0.049 kg), while Jigari recorded the lowest per-panicle grain yield (0.024 kg; 0.026 kg) at both locations (Table 1).

The superior per-panicle yield of Samsorg 53 reflects its enhanced sink capacity for grain production, consistent with findings by Toudou Daouda, Heynikoye Tahirou, Atta, and Bakasso (2025), who documented strong positive associations between panicle characteristics and grain yield among sorghum genotypes. The poor performance of Jigari, despite its tall stature, indicates inefficient assimilate partitioning towards grain, a characteristic common among unimproved landraces (Ajeigbe et al., 2018).

Wider spacing (75 cm×45 cm) produced significantly higher grain yield per panicle than closer spacings at both locations (0.071 kg vs. 0.051 kg at Yola; 0.074 kg vs. 0.053 kg at Ganye), reflecting the positive effect of reduced competition on assimilate availability per plant and improved grain filling. This agrees with Houx et al. (2025), who reported that reduced population densities enhanced reproductive development through greater assimilate availability per plant. The Ganye location consistently recorded higher grain yield per panicle than Yola across all treatments, reflecting the influence of more favorable environmental conditions on individual plant productivity.

Table 1: Effect of varieties and intra-row spacings on grain yield per panicle (kg) of sorghum at Yola and Ganye, during 2025 rainy season.

Treatment	Yola	Ganye
Varieties		
Jigari	0.024	0.026
Kaura	0.047	0.049
SC-XP104	0.057	0.060
Samsorg 53	0.115	0.120
Fp	**<0.001**	**<0.001**
LSD	0.001	0.001
Spacings		
75 cm× 25 cm	0.051	0.053
75 cm× 35 cm	0.061*	0.064
75 cm× 45 cm	0.071	0.074
Fp	**<0.001**	**<0.001**
LSD	0.001	0.001
Variety× Spacing	0.001057	0.001110

NS = Not Significant; * = Slightly Significant; ** = Significant; *** = Highly Significant; LSD = Least Significant Difference at $P \leq 0.05$

The variety×spacing interaction for grain yield per panicle was highly significant at both locations (Yola: 0.001057; Ganye: 0.001110) as presented in Table 2. Samsorg 53 at 75 cm×45 cm recorded the highest interaction mean (0.1342 kg at Yola; 0.141 kg at Ganye), while Jigari at 75 cm×25 cm recorded the lowest (0.021 kg at Yola; 0.022 kg at Ganye). This significant interaction confirms that the response of per-panicle yields to spacing is variety-dependent, consistent with observations by Maina et al. (2024), who emphasized that optimal spacing must be tailored to genotypic characteristics to maximize sorghum yield components.

Table 2: Interaction between varieties and intra-row spacings for grain yield per panicle (kg) of sorghum at Yola and Ganye, during 2025 rainy season.

Variety	75 cm×25 cm	75 cm×35 cm	75 cm×45 cm
Jigari	0.021 / 0.022	0.025 / 0.026	0.028 / 0.030
Kaura	0.039 / 0.041	0.047 / 0.049	0.054 / 0.057
SC-XP104	0.048 / 0.050	0.058 / 0.060	0.067 / 0.070
Samsorg 53	0.095 / 0.100	0.115 / 0.120	0.134 / 0.141

Values presented as Yola / Ganye.

Grain Yield Per Plot (kg)

Grain yield per plot was highly significantly ($P \leq 0.001$) influenced by variety, spacing, and their interaction at both locations as shown in Table 3. Samsorg 53 produced the highest yield per plot (4.985 kg at Yola; 5.234 kg at Ganye), followed by SC-XP104 (2.502 kg; 2.627 kg) and Kaura (2.029 kg; 2.130 kg), while Jigari recorded the lowest (1.065 kg; 1.118 kg) at both locations. These consistent varietal differences across locations confirm strong genetic control of productivity, as reported by Zhang, Wang, Li, Zhang, and Yang (2025) in their multi-location evaluation of sorghum varieties across diverse ecological zones in China.

Closer spacing (75 cm×25 cm) produced significantly higher yield per plot (3.240 kg at Yola; 3.402 kg at Ganye) compared to 75 cm×35 cm (2.430 kg; 2.551 kg) and 75 cm×45 cm (2.266 kg; 2.379 kg). This demonstrates the compensatory effect of plant population on plot-level yield, where increased plant numbers per unit area offset the reduced per-plant productivity associated with higher competition. Ciampitti (2021) similarly reported that closer intra-row spacings in sorghum systems led to improved plot-level yields through enhanced canopy coverage and land use efficiency.

Table 3: Effect of varieties and intra-row spacings on grain yield per plot (kg) of sorghum at Yola and Ganye, during 2025 rainy season

Treatment	Yola	Ganye
Varieties		
Jigari	1.065	1.118
Kaura	2.029	2.130
SC-XP104	2.502	2.627
Samsorg 53	4.985	5.234
Fp	**<0.001**	**<0.001**
LSD	0.030	0.031
Spacings		
75 cm × 25 cm	3.240	3.402
75 cm × 35 cm	2.430	2.551
75 cm × 45 cm	2.266	2.379
Fp	**<0.001**	**<0.001**
LSD	0.026	0.027
Variety× Spacing	0.052	0.055

NS = Not Significant; * = Slightly Significant; ** = Significant; *** = Highly Significant; LSD = Least Significant Difference at $P \leq 0.05$

The highly significant variety spacing interaction for yield per plot (LSD Yola = 0.052; LSD Ganye = 0.055) as shown in Table 4 confirms genotype-dependent density responses. Samsorg 53 at 75 cm×25 cm recorded the highest interaction mean (6.08 kg at Yola; 6.384 kg at Ganye), while Jigari at 75 cm×45 cm recorded the lowest (0.902 kg; 0.947 kg). This agrees with Maina et al. (2024), who observed significant genotype×environment interactions in sorghum yield evaluations. Ganye consistently recorded higher yield per plot than Yola across all treatment combinations, attributed to superior soil moisture conditions and more favorable environmental factors for crop development.

Table 4: Interaction between varieties and intra-row spacings for grain yield per plot (kg) of sorghum at Yola and Ganye, during 2025 rainy season.

Variety	75 cm×25 cm	75 cm×35 cm	75 cm×45 cm
Jigari	1.312 / 1.377	0.980 / 1.029	0.902 / 0.947
Kaura	2.496 / 2.621	1.860 / 1.953	1.731 / 1.818
SC-XP104	3.072 / 3.226	2.300 / 2.415	2.134 / 2.241
Samsorg 53	6.080 / 6.384	4.580 / 4.809	4.294 / 4.509

Values presented as Yola / Ganye

Grain Yield Per Hectare (kg ha^{-1})

Grain yield per hectare was highly significantly (P≤0.001) influenced by variety, spacing, and their interaction at both locations as shown in Table 5. Samsorg 53 produced the highest grain yield per hectare (8308.0 kg ha^{-1} at Yola; 8723.3 kg ha^{-1} at Ganye), significantly superior to all other varieties. SC-XP104 ranked second (4170.2 kg ha^{-1};4378.9 kg ha^{-1}), followed by Kaura (3381.7 kg ha^{-1};3550.7 kg ha^{-1}), while Jigari recorded the lowest yield (1774.6 kg ha^{-1};1862.8 kg ha^{-1}) at both locations. The superior adaptability and yield stability of Samsorg 53 across both locations demonstrates its broad genotypic adaptability for rainfed conditions in Adamawa State.

The yield advantage of improved varieties (Samsorg 53 and SC-XP104) over the local landrace (Jigari) aligns with findings by Ndjeunga, Mausch, and Simtowe (2015), who reported that improved varieties consistently outperformed landraces under improved agronomic management. The consistently low yield of Jigari confirms the limitations of traditional landraces noted by Ajeigbe et al. (2018), including low yield potential and non-responsiveness to improved management. The marked yield difference between Jigari (1774.6 kg ha^{-1}) and Samsorg 53 (8308.0 kg ha^{-1}) at Yola (4.68-fold difference) underscores the importance of variety selection as a foundational decision in sorghum production.

Table 5: Effect of varieties and intra-row spacings on grain yield per hectare (kg ha^{-1}) of sorghum at Yola and Ganye, during 2025 rainy season

Treatment	Yola	Ganye
Varieties		
Jigari	1774.6	1862.8
Kaura	3381.7	3550.7
SC-XP104	4170.2	4378.9
Samsorg 53	8308.0	8723.3
Fp	**<0.001**	**<0.001**
LSD	50.12	52.48
Spacings		
75 cm× 25 cm	5400.0	5669.7
75 cm× 35 cm	4050.0	4252.4
75 cm× 45 cm	3775.8	3964.7
Fp	**<0.001**	**<0.001**
LSD	43.41	45.45
Variety× Spacing	86.82	90.90

NS = Not Significant; * = Slightly Significant; ** = Significant; *** = Highly Significant; LSD = Least Significant Difference at $P \leq 0.05$

Among spacing treatments, 75 cm×25 cm produced significantly higher grain yield per hectare at both locations (5400.0 kg ha^{-1} at Yola; 5669.7 kg ha^{-1} at Ganye) compared to 75 cm×35 cm (4050.0 kg ha^{-1};4252.4 kg ha^{-1}) and 75 cm×45 cm (3775.8 kg ha^{-1};3964.7 kg ha^{-1}). The population-yield compensation effect described by Houx et al. (2025) is clearly demonstrated here: despite lower per- plant productivity under higher density, the increased plant population under closer spacing more than compensates, resulting in greater total grain production per unit area. This is consistent with the principle that yield per hectare is determined by the product of plants per unit area and yield per plant.

The highly significant variety×spacing interaction for yield per hectare (LSD = 86.82 at Yola; 90.90 at Ganye) confirms genotype-dependent density responses as shown in Table 6. Samsorg 53 at 75 cm×25 cm recorded the highest interaction mean (10133.3 kg ha^{-1} at Yola; 10640.0 kg ha^{-1} at Ganye), while Jigari at 75 cm×45 cm recorded the lowest (1503.9 kg ha^{-1};1578.9 kg ha^{-1}). These interactions confirm that Samsorg 53 and Kaura possess the genetic capacity to exploit higher plant populations for superior grain yield, while Jigari demonstrated consistently poor performance regardless of spacing. This is consistent with findings by Zhang et al. (2025) and Maina et al. (2024), who reported significant genotype density interactions in sorghum yield evaluations.

Table 6: Interaction between varieties and intra-row spacings for grain yield per hectare (kg ha^{-1}) of sorghum at Yola and Ganye, during 2025 rainy season.

Variety	75 cm×25 cm	75 cm×35 cm	75 cm×45 cm
Jigari	2186.7 / 2295.0	1633.3 / 1714.4	1503.9 / 1578.9
Kaura	4160.0 / 4367.7	3100.0 / 3255.0	2885.0 / 3029.4
SC-XP104	5120.0 / 5376.1	3833.3 / 4025.0	3557.2 / 3735.6
Samsorg 53	10133.3 / 10640.0	7633.3 / 8015.0	7157.2 / 7515.0

Values presented as Yola / Ganye.

One Thousand Seed Weight (kg)

One thousand-seed weight was highly significantly ($P \leq 0.001$) influenced by variety at both locations, while spacing had a slight to significant effect and the variety×spacing interaction was not significant as shown in Table 7. Kaura recorded the highest 1000-seed weight (0.039 kg at Yola; 0.041 kg at Ganye), followed by Samsorg 53 (0.033 kg; 0.035 kg), Jigari (0.026 kg; 0.031 kg), and SC-XP104, which recorded the lowest (0.025 kg; 0.026 kg) at both locations (Table 7). These differences reflect the genetic diversity among the tested varieties in grain size, consistent with findings by Toudou et al. (2025), who documented significant genotypic variation for thousand-grain weight among sorghum varieties.

Wider spacing (75 cm×45 cm) consistently produced slightly higher 1000-seed weight (0.032 kg at Yola; 0.033 kg at Ganye) compared to 75 cm×25 cm (0.030 kg; 0.031 kg) at both locations. The reduced competition under wider spacing likely enhanced assimilate availability per plant, thereby improving grain filling. However, the relatively small magnitude of spacing effects on 1000-seed weight compared to its effects on yield per panicle and yield per hectare confirms that grain size is a conservative yield component, primarily under genetic control and less responsive to plant density variation, as noted by Chaithrashree, Lakshmeesha, Darshitha, Harish, and Manojkumar (2024), who reported high heritability estimates for seed weight in sorghum.

Table 7: Effect of varieties and intra-row spacings on 1000-seed weight (kg) of sorghum at Yola and Ganye, during 2025 rainy season.

Treatment	Yola	Ganye
Varieties		
Jigari	0.026	0.031
Kaura	0.039	0.041
SC-XP104	0.025	0.026
Samsorg 53	0.033	0.035
Fp	**<0.001**	**<0.001**
LSD	0.000	0.000
Spacings		
75 cm × 25 cm	0.030	0.031
75 cm × 35 cm	0.031	0.032
75 cm × 45 cm	0.032	0.033
Fp	**<0.001**	**<0.001**
LSD	0.000	0.000
Variety× Spacing	0.000306	0.000344

NS = Not Significant; * = Slightly Significant; ** = Significant; *** = Highly Significant; LSD = Least Significant Difference at $P \leq 0.05$

The non-significant variety×spacing interaction for 1000-seed weight (0.000306 at Yola; 0.000344 at Ganye) indicates that although varieties differed in individual seed size and spacing marginally influenced grain filling, the pattern of response to spacing was consistent across all varieties as shown in Table 8. Varietal ranking was stable across spacing treatments, with Kaura maintaining the highest seed weight and SC-XP104 consistently recording the lowest. This suggests that selection for 1000-seed weight would be effective in sorghum breeding programs, as the trait shows predominantly additive genetic control with limited genotype ×environment interaction. These findings are consistent with those of Chaithrashree et al. (2024), who identified direct effects of seed weight on total yield and recommended it as an effective selection criterion in sorghum improvement.

Table 8: Interaction between varieties and intra-row spacings for 1000-seed weight (kg) of sorghum at Yola and Ganye, during 2025 rainy season.

Variety	75 cm×25 cm	75 cm×35 cm	75 cm×45 cm
Jigari	0.025 / 0.026	0.026 / 0.027	0.027 / 0.028
Kaura	0.039 / 0.040	0.039 / 0.041	0.040 / 0.042
SC-XP104	0.024 / 0.025	0.025 / 0.026	0.026 / 0.027
Samsorg 53	0.032 / 0.034	0.033 / 0.035	0.034 / 0.035

Values presented as Yola / Ganye.

Conclusion

This study evaluated the effects of four sorghum varieties and three intra-row spacings on grain yield per panicle, yield per plot, yield per hectare, and 1000-seed weight under rainfed conditions in Adamawa State, Northeastern Nigeria. The results demonstrated significant genetic variability among varieties and significant effects of intra-row spacing on all yield parameters, with highly significant variety×spacing interactions confirming genotype-dependent density responses.

Samsorg 53 consistently recorded the highest grain yield per panicle, per plot, and per hectare at both Yola and Ganye locations, demonstrating its superior genetic yield potential and broad adaptability. Jigari, despite its tall stature, recorded the lowest yields across all parameters, confirming the limitations of unimproved landraces under improved management. Kaura recorded the highest 1000-seed weight, suggesting its potential utility in programmes targeting grain quality. Closer spacing (75 cm×25 cm) maximized grain yield per hectare and per plot, while wider spacing (75 cm×45 cm) enhanced per-plant productivity metrics. The Ganye location consistently outperformed Yola, reflecting the influence of site-specific environmental conditions on sorghum productivity.

Based on these findings, the following recommendations are made for sorghum production in Adamawa State:

i). Samsorg 53 planted at 75 cm×25 cm spacing is recommended for farmers prioritizing maximum grain yield under rainfed conditions;

ii). Kaura at wider spacing (75 cm×35 cm to 75 cm×45 cm) is suitable for dual-purpose (grain and fodder) production systems;

iii). Agricultural extension services should promote variety-specific spacing recommendations rather than uniform plant population guidelines; and (iv) agro-ecologically similar areas to Ganye offer higher yield potential and should be prioritized for sorghum intensification.

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