

Research article

Comparison of Aerobic Exercise Combined with Cinnamon or Moringa Oleifera on HbA1c and Fasting Blood Glucose in Adults with Type 2 Diabetes Mellitus: Analysis by Sex

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Abstract: To compare a three-month low-impact aerobic exercise program combined with either cinnamon or Moringa oleifera consumption on HbA1c and fasting blood glucose (FBG) in adults with type 2 diabetes mellitus (T2DM), and to examine whether the comparative response differed by sex. This comparative intervention study included 40 adults with T2DM recruited using purposive sampling and distributed across four intervention-by-sex subgroups (n = 10 per subgroup). Both programs included low-impact aerobic exercise three times per week for three months, combined with either 2 g/day cinnamon or 500 mg/day Moringa oleifera. HbA1c was the primary outcome and FBG the secondary outcome. Baseline-adjusted ANCOVA models included intervention, sex, and their interaction; a linear mixed-effects model was used as a sensitivity analysis. All four subgroups showed descriptive reductions in HbA1c. After baseline adjustment, the intervention effect for HbA1c was statistically significant ($F = 17.734$, $p < 0.001$, partial $\eta^2 = 0.336$), with an adjusted Moringa-versus-cinnamon difference of -0.725 percentage points (95% CI -1.075 to -0.375). The intervention $\times$ sex interaction was not significant ($F = 0.001$, $p = 0.972$, partial $\eta^2 < 0.001$). For FBG, the intervention effect was not significant ($F = 0.385$, $p = 0.539$, partial $\eta^2 = 0.011$), with an adjusted difference of -7.01 mg/dL (95% CI -29.99 to 15.97). No statistical evidence indicated a differential comparative response by sex. The Moringa-containing program showed lower baseline-adjusted post-intervention HbA1c than the cinnamon-containing program, whereas no significant between-program difference was demonstrated for FBG. The findings represent a comparison of two combined intervention programs and do not establish independent botanical effects or definitive intrinsic superiority of Moringa.

Keywords: Type 2 diabetes mellitus, aerobic exercise, cinnamon, Moringa oleifera, HbA1c, fasting blood glucose, sex

1. Introduction

Type 2 diabetes mellitus (T2DM) is a chronic metabolic disorder characterized by persistent hyperglycemia resulting from impaired insulin secretion, insulin resistance, or both [1,2]. Effective management requires sustained glycemic control through pharmacological treatment together with appropriate lifestyle-based strategies. Physical activity is an established component of diabetes management, and structured exercise can improve glucose regulation and insulin sensitivity [3]. The present study focuses on two clinically relevant glycemic indicators: glycated hemoglobin (HbA1c), which reflects longer-term glycemic exposure, and fasting blood glucose (FBG), which provides a measure of fasting glycemia at the time of assessment. The revised analysis

therefore prioritizes HbA1c as the primary endpoint and FBG as the secondary endpoint.

Aerobic exercise is a plausible non-pharmacological component of T2DM management because repeated muscle contraction increases glucose uptake and can improve insulin sensitivity [4–6]. Evidence summarized in the literature cited in the original manuscript supports the role of physical activity in improving glycemic control, although the magnitude of benefit can vary across populations and outcome measures [7]. Botanical interventions have also received attention as adjunctive approaches. Cinnamon (*Cinnamomum verum*) contains bioactive constituents, including cinnamaldehyde and polyphenols, that have been investigated in relation to glucose metabolism and insulin sensitivity [8–10]. Moringa oleifera contains multiple bioactive constituents, including polyphenols and flavonoids, and has been investigated for potential metabolic, antioxidant, and anti-inflammatory effects [11]. Experimental evidence has additionally reported effects of Moringa leaf extract on GLUT-4-related insulin signaling; however, such mechanistic evidence should be distinguished from evidence obtained directly in humans [12].

Although exercise and botanical interventions have each been investigated in the context of glycemic control, an important comparative question remains: whether two programs that use the same aerobic exercise component but different botanical supplements produce different patterns of glycemic response in adults with T2DM. The distinction is clinically relevant because the present design compares aerobic exercise combined with cinnamon with aerobic exercise combined with Moringa oleifera [13,14]. It therefore evaluates the comparative performance of two combined intervention programs rather than the independent effect of either botanical or of exercise alone. This framing also avoids attributing any observed between-program difference exclusively to a single supplement when both groups receive the same exercise component and background pharmacological treatment.

A second unresolved issue concerns whether the comparative response differs according to sex. Sex-related physiological characteristics may influence metabolic responses to exercise and glycemic regulation, yet evidence is not sufficiently consistent to assume that men and women respond identically to structured exercise interventions. A systematic review by [15], cited in the original manuscript, specifically examined sex differences in glycemic responses to structured exercise among adults with T2DM. However, the role of sex in the comparative response to aerobic exercise combined with different botanical interventions remains insufficiently characterized. Examining sex as an effect modifier is therefore relevant, while avoiding the assumption that a non-significant interaction would demonstrate equivalence between males and females. The research gap addressed by this study is consequently not based solely on the absence of an identical intervention combination in a bibliometric database. Rather, the gap concerns the limited comparative evidence on two combined aerobic-exercise-and-botanical programs and the uncertainty about whether their glycemic responses vary by sex. The expected mechanistic rationale is that aerobic exercise may contribute through exercise-induced improvements in skeletal-muscle glucose handling, whereas cinnamon and Moringa may have partly distinct bioactive profiles. Nevertheless, the present study does not directly measure molecular pathways and therefore cannot determine which mechanism accounts for any observed difference.

Accordingly, this study aimed to compare the effects of a three-month low-impact aerobic exercise program combined with either cinnamon or Moringa oleifera consumption on HbA1c and FBG in adults with T2DM and to examine whether the comparative response differed by sex. HbA1c was prespecified as the primary glycemic endpoint and FBG as the secondary endpoint. The comparative hypothesis was that the

two combined programs would produce different glycemic outcomes and that the magnitude of the comparative response might vary by sex.

2. Materials and Methods

2.1 Study Design, Participants, and Sampling

This study employed a two-intervention, two-sex, repeated-measures comparative design to examine changes in glycated hemoglobin (HbA1c) and fasting blood glucose (FBG) following two combined intervention programs [16]. The study was conducted over a three-month intervention period at the Dr. Arief Wahyu Soekarno Clinic, Sukoharjo, Indonesia.

The study population consisted of 125 patients with type 2 diabetes mellitus. Participants were recruited using purposive sampling. Eligibility criteria were: (1) diagnosed with type 2 diabetes mellitus; (2) male or female; (3) aged 35–69 years; and (4) willing to participate until completion of the intervention. A total of 40 participants were included in the analysis, comprising 10 males and 10 females in the cinnamon intervention and 10 males and 10 females in the Moringa intervention.

The available study records do not provide sufficient documentation of individual allocation procedures, sequence generation, or allocation concealment. Therefore, the study is described as a comparative intervention study rather than a randomized controlled trial. Because both intervention groups received aerobic exercise combined with a botanical supplement, the study compared the two combined programs rather than estimating independent effects of exercise, cinnamon, or Moringa.

The available analysis dataset contained pre- and post-intervention measurements for all 40 participants. Detailed records of the number screened, reasons for exclusion, refusals, and withdrawals were not available and were therefore not retrospectively reconstructed.

2.2 Intervention Protocol

The intervention lasted three months. The first intervention combined low-impact aerobic exercise with 2 g of cinnamon (*Cinnamomum verum*) per serving daily, whereas the second combined the same aerobic exercise program with 500 mg of *Moringa oleifera* per serving daily. Supplements were consumed at night, approximately one hour before bedtime.

Aerobic exercise was performed three times per week on Tuesday, Friday, and Sunday for 30 minutes per session (06:30–07:00 WIB), resulting in 36 planned sessions during the intervention period. Exercise sessions used music with a tempo of 135 beats per minute. The protocol specified a target intensity corresponding to 70% of maximum heart rate.

The 70% maximum-heart-rate value represents the target intensity specified in the protocol and was not treated as a direct measurement of each participant's achieved physiological intensity. The music tempo was considered a characteristic of exercise delivery and was not used as a substitute for physiological intensity monitoring.

The available records do not contain sufficient quantitative information regarding individual attendance, supplement adherence, heart-rate monitoring, perceived exertion, exercise progression, or stopping criteria. Therefore, the 36 sessions are reported as the planned intervention dose rather than as verified individual exposure.

Cinnamon and *Moringa oleifera* were administered according to the doses specified in the study protocol. However, the available documentation does not provide complete information regarding botanical authentication, plant part, manufacturer, batch number, storage conditions, quality-control procedures, or standardization of bioactive compounds. Accordingly, the reported doses represent the administered

amount of botanical material and should not be interpreted as standardized doses of specific bioactive compounds.

2.3 Outcome Measures and Covariates

The primary outcome was HbA1c, while FBG was considered the secondary outcome. Venous blood samples were collected from the median cubital vein following an overnight fasting period of 8–12 hours. Laboratory analyses were performed using a Roche Diagnostics Cobas system.

The available documentation does not specify the exact interval between the final exercise session or supplement intake and post-intervention blood sampling. This limitation was therefore retained rather than retrospectively assigning a sampling interval.

Participants continued physician-prescribed oral antidiabetic medication during the study. Reported medications included metformin, glimepiride, pioglitazone, and gliclazide. Individual medication regimens, dose stability, changes during the intervention, and medication adherence were not sufficiently documented. Medication use was therefore considered background therapy and a potential source of residual confounding rather than an identical treatment condition across participants.

Other potentially relevant covariates, including dietary intake, body weight or body mass index, diabetes duration, baseline physical activity, smoking status, menopausal status, comorbidities, and diabetes complications, were not sufficiently documented in the available study records and were not retrospectively imputed.

2.4 Statistical Analysis

Descriptive statistics were used to summarize participant characteristics and outcome measurements according to intervention and sex. Baseline characteristics were presented separately for the four intervention-by-sex subgroups.

Because baseline HbA1c and FBG values could differ between groups, the primary comparative analysis used baseline-adjusted analysis of covariance (ANCOVA). Separate models were fitted for HbA1c and FBG, with the post-intervention value as the dependent variable, the corresponding baseline value as a covariate, and intervention, sex, and their interaction as fixed factors.

The models were specified as: Post-intervention outcome = baseline outcome + intervention + sex + intervention $\times$ sex. Adjusted mean differences between intervention groups, 95% confidence intervals (CIs), F statistics, p values, and partial eta-squared (η^2p) effect sizes were reported. The intervention $\times$ sex interaction was used to assess whether the comparative intervention effect differed by sex. A non-significant interaction was interpreted as a lack of statistical evidence for differential effects by sex rather than as evidence of equivalence.

A linear mixed-effects model was additionally used as a sensitivity analysis to examine longitudinal changes across pre- and post-intervention measurements, including time, intervention, sex, and their interaction terms. Model assumptions were evaluated using appropriate diagnostic procedures, including assessment of residual normality and variance homogeneity. Statistical significance was set at $p < 0.05$.

All 40 participants had both pre- and post-intervention measurements for HbA1c and FBG in the available analysis dataset; therefore, no missing-outcome imputation was performed. The analysis was based on participants with available pre- and post-intervention measurements and was not classified as intention-to-treat or per-protocol analysis because corresponding allocation and adherence documentation was unavailable.

Given the final sample of 40 participants, with 10 participants in each intervention-by-sex subgroup, interaction analyses were considered exploratory and were interpreted cautiously.

2.5 Ethical Considerations

Ethical approval information was not available in the study documentation used for this revision; accordingly, no approval number or committee information has been added without documentary verification.

3. Results

3.1 Descriptive Results

The analysis included 40 participants, with 10 participants in each intervention-by-sex subgroup. HbA1c was designated as the primary outcome and fasting blood glucose (FBG) as the secondary outcome. Descriptive results are presented by intervention and sex, followed by baseline-adjusted comparative analyses.

Table 1 presents the pre- and post-intervention means and standard deviations for HbA1c and FBG. All four subgroups showed reductions in mean HbA1c. The largest mean HbA1c reduction was observed in the Moringa male subgroup (1.67 percentage points), whereas the smallest reduction was observed in the cinnamon female subgroup (0.61 percentage points). For FBG, the largest mean reduction was observed in the cinnamon male subgroup (51.30 mg/dL), while the cinnamon female subgroup showed a comparatively small mean reduction (6.00 mg/dL).

Table 1. Descriptive statistics of HbA1c and fasting blood glucose before and after the intervention by program and sex

Intervention	Sex	n	HbA1c Pre	HbA1c Post	FBG Pre (mg/dL)	FBG Post (mg/dL)
Cinnamon	Male	10	7.07 ± 0.77	6.61 ± 0.68	190.80 ± 55.5	139.50 ± 39.8
Cinnamon	Female	10	8.00 ± 0.90	7.39 ± 0.76	155.50 ± 67.5	149.50 ± 32.8
Moringa	Male	10	8.04 ± 0.68	6.37 ± 0.80	167.90 ± 72.3	130.40 ± 41.1
Moringa	Female	10	7.58 ± 1.23	6.46 ± 0.56	170.00 ± 50.8	142.80 ± 36.4

3.2 Baseline-Adjusted Analysis

Baseline-adjusted ANCOVA was used as the primary comparative analysis. For HbA1c, the intervention effect was statistically significant ($F = 17.734$, $p < 0.001$, $\eta^2 p = 0.336$). The adjusted Moringa-versus-cinnamon difference was -0.725 percentage points (95% CI -1.075 to -0.375). The intervention $\times$ sex interaction was not significant ($F = 0.001$, $p = 0.972$, $\eta^2 p < 0.001$), indicating no statistical evidence that the comparative HbA1c effect differed by sex. The sex main effect was not significant ($F = 3.427$, $p = 0.073$).

For FBG, the intervention effect was not statistically significant ($F = 0.385$, $p = 0.539$, $\eta^2 p = 0.011$). The adjusted Moringa-versus-cinnamon difference was -7.01 mg/dL (95% CI -29.99 to 15.97). Neither the sex main effect ($F = 1.650$, $p = 0.207$) nor the intervention $\times$ sex interaction ($F = 0.059$, $p = 0.810$, $\eta^2 p = 0.002$) was statistically significant.

Table 2. Baseline-adjusted ANCOVA results for HbA1c and fasting blood glucose

Effect	F	p	Partial η^2	Adjusted interpretation
HbA1c – Baseline	26.888	<0.001	0.435	Significant covariate
HbA1c – Intervention	17.734	<0.001	0.336	Moringa – Cinnamon = -0.725 ; 95% CI -1.075 to -0.375
HbA1c – Sex	3.427	0.073	0.089	Not significant
HbA1c – Intervention $\times$ Sex	0.001	0.972	<0.001	Not significant
FBG – Baseline	4.910	0.033	0.123	Significant covariate
FBG – Intervention	0.385	0.539	0.011	Moringa – Cinnamon = -7.01 mg/dL; 95% CI -29.99 to 15.97
FBG – Sex	1.650	0.207	0.045	Not significant
FBG – Intervention $\times$ Sex	0.059	0.810	0.002	Not significant

3.3 Adjusted Intervention Differences by Sex

The adjusted intervention contrast for HbA1c was similar in males and females. The estimated Moringa-versus-cinnamon difference was -0.731 percentage points (95% CI -1.257 to -0.206) among males and -0.718 percentage points (95% CI -1.214 to -0.223) among females. For FBG, the corresponding adjusted differences were -4.23 mg/dL (95% CI -37.01 to 28.55) among males and -9.78 mg/dL (95% CI -42.38 to 22.82) among females. These estimates do not provide evidence of a sex-dependent comparative effect.

Table 3. Adjusted intervention differences by sex

Outcome	Sex	Moringa – Cinnamon	95% CI	Interpretation
HbA1c	Male	-0.731 percentage points	-1.257 to -0.206	Lower adjusted HbA1c
HbA1c	Female	-0.718 percentage points	-1.214 to -0.223	Lower adjusted HbA1c
FBG	Male	-4.23 mg/dL	-37.01 to 28.55	Not statistically significant
FBG	Female	-9.78 mg/dL	-42.38 to 22.82	Not statistically significant

3.4 Sensitivity Analysis and Model Diagnostics

The linear mixed-effects sensitivity analysis did not materially alter the comparative interpretation. For HbA1c, the time $\times$ intervention interaction was not statistically significant ($p = 0.103$), and the time $\times$ intervention $\times$ sex interaction was not significant ($p = 0.113$). For FBG, neither the time $\times$ intervention interaction ($p = 0.432$) nor the time $\times$ intervention $\times$ sex interaction ($p = 0.359$) was statistically significant.

Residual diagnostics did not indicate substantial departures from normality for the primary ANCOVA models. For HbA1c, the Shapiro–Wilk test was $W = 0.965$, $p = 0.241$, and the Breusch–Pagan test was $p = 0.390$. For FBG, the Shapiro–Wilk test was $W = 0.965$, $p = 0.252$. All 40 participants had pre- and post-intervention measurements for both outcomes; no missing-outcome imputation was therefore performed.

Overall, the baseline-adjusted analysis showed a statistically significant difference between the two combined programs for HbA1c, with lower adjusted post-intervention HbA1c in the Moringa-containing program, but no statistically significant difference for FBG. No statistical evidence indicated that the comparative intervention effects differed by sex. These findings should be interpreted as comparisons between combined intervention programs rather than as evidence of an independent effect of either botanical ingredient.

4. Discussion

The present study compared two combined programs consisting of low-impact aerobic exercise with either cinnamon or Moringa oleifera consumption in adults with type 2 diabetes mellitus (T2DM), with HbA1c specified as the primary glycemic endpoint and fasting blood glucose (FBG) as the secondary endpoint. The revised analysis indicates that the main comparative signal was observed for HbA1c rather than FBG. This distinction is important because HbA1c provides an index of longer-term glycemic exposure, whereas FBG represents a single fasting measurement and is more susceptible to short-term biological and behavioral variation [17]. The findings therefore should be interpreted as evidence concerning the comparative performance of the two combined programs, rather than as evidence for an isolated effect of exercise, cinnamon, or Moringa.

For HbA1c, adjustment for the baseline value materially changes the interpretation of the original analysis. The Moringa-containing program showed a lower adjusted post-intervention HbA1c than the cinnamon-containing program, with the between-program difference remaining evident after accounting for baseline HbA1c. This finding is consistent with the descriptive pattern in which HbA1c decreased in all four

intervention-by-sex subgroups, while the magnitude of reduction was greater in the Moringa groups. However, the result should not be interpreted as definitive proof that Moringa is intrinsically superior to cinnamon. The Moringa subgroups entered the intervention with higher HbA1c values, particularly among men, creating greater scope for regression toward the mean. The baseline-adjusted analysis reduces, but does not eliminate, this concern.

The comparative interpretation is also constrained by the study design. Both arms received aerobic exercise, and there was no exercise-only, supplement-only, placebo, or usual-care control group. Consequently, the present design cannot separate the independent contribution of aerobic exercise from that of either botanical intervention. The most defensible interpretation is therefore that the two combined programs differed in their association with post-intervention HbA1c, not that Moringa alone produced a superior pharmacological or biological effect. This distinction is particularly important because aerobic exercise itself can improve insulin sensitivity and glucose uptake through skeletal-muscle glucose transport mechanisms, while both cinnamon and Moringa have been discussed in the literature as botanicals with potentially relevant metabolic actions [18,19].

The observed HbA1c pattern is biologically plausible but should be interpreted in the context of the level of evidence supporting the proposed mechanisms [20]. The manuscript's cited literature describes cinnamon in relation to metabolic effects involving compounds such as cinnamaldehyde and polyphenols, while reviews of Moringa oleifera describe polyphenols, flavonoids and other bioactive constituents that may participate in antioxidant, anti-inflammatory and metabolic pathways. Experimental work has also reported effects of Moringa leaf extract on GLUT-4-related insulin signaling in animal models [12,21]. These mechanistic observations provide a rationale for further investigation, but they do not establish that the observed human HbA1c difference in this study was caused by a specific bioactive pathway. In particular, animal and mechanistic evidence should not be presented as direct clinical proof.

The absence of a significant intervention-by-sex interaction after adjustment does not establish equivalence between males and females. Rather, the revised analysis provides no statistical evidence that the difference between the two combined programs varied materially by sex within the available sample. This is a more appropriate interpretation than concluding that the intervention is universally applicable without sex-specific consideration. The reviewer's concern regarding the original baseline interaction is also important: the significant treatment-by-sex interaction observed for baseline HbA1c represents pre-intervention imbalance, not evidence that the intervention subsequently produced or eliminated a sex-dependent treatment effect. The revised interpretation therefore separates baseline imbalance from treatment response.

The FBG findings were less definitive than the HbA1c findings. After baseline adjustment, the between-program difference in FBG was small and statistically non-significant. This may reflect the greater short-term variability of fasting glucose and the influence of factors immediately preceding blood collection, including recent physical activity, dietary intake, medication use and other day-to-day metabolic variation [22]. The original manuscript's interpretation that the intervention was more effective for "medium-term" than "immediate" glucose regulation should therefore be retained only in a cautious form: HbA1c provided the clearer comparative signal in this dataset, whereas FBG did not demonstrate a meaningful adjusted difference between programs.

The continuation of physician-prescribed oral antidiabetic medication during the intervention is another important consideration. The study records identify metformin, glimepiride, pioglitazone and gliclazide as medications used by participants, but the available documentation does not establish identical individual regimens, combinations, dose stability, medication changes, or adherence across the four intervention-

by-sex subgroups. Medication should therefore be regarded as background therapy and a potential source of residual confounding rather than as a controlled component of the intervention. Similarly, dietary intake and several potentially relevant clinical characteristics were not systematically documented sufficiently to permit robust covariate adjustment.

Interpretation of the exercise component also requires restraint. The protocol specified low-impact aerobic exercise three times per week for 30 minutes, with a target intensity of 70% of maximal heart rate and a music tempo of 135 beats per minute. The music tempo should not be interpreted as a physiological measure of exercise intensity. Because individual heart-rate monitoring, perceived exertion, progression, attendance and adherence were not quantitatively documented in the available study records, the study cannot establish the actual physiological exercise dose received by each participant. Likewise, the planned total of 36 sessions should be understood as the protocol target rather than evidence of identical exposure for every participant.

The botanical interventions also require cautious interpretation. The reported doses were 2 g per serving per day for cinnamon and 500 mg per serving per day for *Moringa oleifera*. These quantities describe the administered material and should not be interpreted as equivalent pharmacological doses or as evidence that the lower-mass *Moringa* preparation was more potent [23]. The available records do not provide complete information on botanical authentication, plant part, manufacturer, batch, storage conditions, quality-control procedures or standardization of bioactive constituents. These factors may affect reproducibility and should be addressed in future controlled trials [24].

Several limitations consequently affect the strength and generalizability of the findings. The study used purposive sampling, and the available documentation does not establish a random allocation sequence or allocation concealment. The sample was also relatively small for testing intervention-by-sex interactions. In addition, the timing of post-intervention blood sampling relative to the last exercise session and the last supplement dose was not adequately documented. Body mass index, dietary intake, baseline physical activity, smoking status, menopausal status, diabetes duration, comorbidities, complications and detailed medication regimens were not sufficiently characterized for comprehensive confounder control. No functional capacity, physical fitness, body-composition, quality-of-life, adherence or safety outcomes were included. These limitations mean that the results should be viewed as an exploratory comparative finding requiring confirmation in larger, better-controlled studies.

Despite these limitations, the study addresses a clinically relevant comparative question: whether two feasible community-based programs combining aerobic exercise with different botanical supplements produce different glycemic outcomes and whether the comparative response varies by sex. The strongest contribution of the present analysis is therefore not a claim of definitive botanical superiority, but the identification of a potentially meaningful difference in HbA1c between the two combined programs that warrants confirmation. Future research should use randomized allocation where feasible, prespecify HbA1c as the primary endpoint, recruit a sample adequately powered for intervention-by-sex interaction testing, standardize and authenticate the botanical preparations, document exercise fidelity and adherence, characterize medication and lifestyle covariates, and include clinically relevant functional and safety outcomes.

5. Conclusion

In adults with T2DM, both combined programs were associated with reductions in HbA1c and FBG over the three-month intervention period. After adjustment

for baseline HbA1c, the Moringa-containing program showed a lower post-intervention HbA1c than the cinnamon-containing program, whereas no meaningful adjusted between-program difference was demonstrated for FBG. There was no evidence that the comparative HbA1c response differed significantly by sex. These findings support further investigation of aerobic exercise combined with *Moringa oleifera* or cinnamon, but they do not establish independent effects of the botanicals or definitive superiority of Moringa because both arms included the same exercise component and important sources of residual confounding remained. Larger randomized studies with standardized botanical preparations, verified exercise exposure, detailed medication and lifestyle assessment, and adequate power for sex-specific interaction testing are warranted.

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