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Genetic and economic evaluation of alternative breeding schemes for two indigenous goat populations of Ethiopia

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ABSTRACT
In this study, breeding objective traits were identified, and alternative breeding schemes were simulated and evaluated for two goat populations. The traits were as follows: body size, twinning ability and kidding interval (KI) for Arab goats and body size, twinning ability and mothering ability for Oromo goats. The selection criteria were six-month weight (6mw, kg), litter size at birth (LSB), litter size at weaning (LSW) and KI (days). The schemes were as follows: (1) Scheme 1: 2 years of buck use and 10% selection proportion, (2) Scheme 2: 2 years of buck use and 15% selection proportion, (3) Scheme 3: 3 years of buck use and 10% selection proportion, and (4) Scheme 4: 3 years of buck use and 15% selection proportion. The predicted annual genetic gain (PAGG) for 6mw ranged from 0.29 to 0.32 kg for Arab goats while it varied from 0.34 to 0.38 kg for Oromo goats. On the contrary, the PAGGs for LSB and LSW for both populations were considerably small regardless of the different schemes. The economic return (Euro/doe) ranged from 0.99 to 1.15 for Arab goats and from 0.60 to 0.70 for Oromo goats. SCM2 is recommended over other schemes.

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Breeding scheme; deterministic approach; Ethiopia; genetic gain; simulation

Introduction

The goat population of Ethiopia is estimated to be 52.46 million heads (CSA 2021), and the number of goats used to be considerably smaller than the number of sheep. However, very recently, the goat-to-sheep ratio showed an increasing trend; 0.93 (CSA 2012), 0.99 (CSA 2015), 0.98 (CSA 2017), 1.12 (CSA 2020) and 1.22 (CSA 2021) which might indicate that goats are becoming more important than sheep in Ethiopia. Almost all goats are managed by smallholder farmers and pastoralists under traditional production systems. They provide multiple functions for their owners such as source of income, food, and raw materials (skins). They also serve as means of risk mitigation during crop failures, savings and investments in addition to other socio-economic and cultural functions (Legese et al. 2014).

Although a large number of goats are found in Ethiopia, the productivity per animal and flock off-take however are low. For instance, recent estimates of the average annual off-take rate for the years 2008–2010 indicate values between 30% and 38% (Legese and Fadiga 2014). Similarly, during the year 2013, goats contributed only 11.0 and 1.4% of the annual national meat and milk production, respectively (FAOSTAT 2016). Many interrelated factors including lack of suitable breeding programs contribute for the low productivity of indigenous goats.

Genetic improvement strategies, aimed at improving the production and reproduction potential of indigenous goats, have been executed in Ethiopia since the beginning of goat research in the mid-1970s. The most common strategy was centralized breeding scheme, usually nucleus breeding units, established at on-station and entirely managed and controlled by government organizations with minimal, if any, participation by the farmers (Haile et al. 2018). Although well intended, the schemes failed to provide sufficient number and quality of improved males and also failed to engage the participation of the end users in the process (Haile et al. 2020). Another widely followed strategy was crossbreeding of indigenous goat breeds with imported exotic breeds in the form of semen, embryos or live animals. In most cases, this is done with very little consideration of the needs, views and indigenous practices of the farmers and their limited or no participation from planning to execution of the programs (Ayalew et al. 2003). Insufficient pretesting of the suitability and adaptability of the exotic breeds and their resulting crosses to local production systems, poor management and low input production systems were also some of the limitations of the programs (Haile et al. 2020). As a result, genetic erosion of the local breeds has occurred where indiscriminate crossbreeding with local populations was practiced (Haile et al. 2018).

A recent alternative approach is community-based breeding program (CBBP). Such programs consider the needs, views, decisions and active participation of farmers from inception through to implementation (Haile et al. 2020). A promising option for designing CBBP, where communal grazing and watering points are customary, is to consider the village population as one large flock or a breeding unit. In this case,

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breeding animals are being selected based on phenotypes recorded within the village population. The primary aim of a breeding program for smallholder conditions should be to minimize the risk by developing cost and resource saving production methods, while achieving acceptable genetic gain in important breeding traits (Sölkner et al. 1998). In Ethiopia, CBBPs have been established since 2009; for sheep (Gizaw et al. 2009; Duguma et al. 2011; Mirkena et al. 2012) and goats (Abegaz et al. 2014; Alubel 2015; Zergaw et al. 2016; Jembere et al. 2019).

The present study simulated the most appropriate breeding schemes for two indigenous goat populations in two agro-ecologies in northwestern Ethiopia. The simulations were based on comprehensive studies of production systems and phenotypic ranking experiments (Oumer et al. 2019; Oumer et al. 2021).

Materials and methods

Description of the study areas

Genetic and economic evaluation of the alternative breeding schemes targeted Arab and Oromo goat populations in Benishangul Gumuz region, northwestern Ethiopia. The locations, Homosha and Bambasi, are believed to be the breeding tracts for Arab and Oromo goat populations, respectively. Homosha has semi-arid agro-ecology with average annual temperature that varies from 20°C to 30°C. The rainfall pattern of the area is erratic and uneven with a mean annual range of 700–1200 mm. It covers around 645.78 km^2, positioned from 6° 44′ to 6° 84′ north latitude and from 37° 92′ to 38° 6′ east longitude at an average latitude of 1373 masl (elevationmap.net 2018). The area is characterized by limited crop production due to poor soil fertility (Homosha BoARD 2018).

Bambasi has sub-humid agro-ecology with geographical coordinates of 9° 45′ north latitude and 34° 44′ east longitude with an elevation of 1668 masl (Latitude.to, maps, geolocated articles, latitude longitude coordinate conversion 2018). The mean annual rainfall ranges from 900 to 1500 mm and the average annual temperature is 28°C. The total area coverage is 2210.16 km^2. The production system is mixed crop-livestock system with high priority of Oromo goat production (Bambasi BoARD 2018). Description of the two goat populations is given in Table 1.

Selection of villages

Multistage stratified purposive sampling was employed to select villages/peasant associations (PAs) – the lowest administrative units in Ethiopia. Four villages were selected from each district based on goat population size (≥300 breeding does per village) (using previous flock inventory results taken from each village and secondary data from the respective districts' agricultural offices), presence of communal grazing areas, relative significance of goats to the livelihood of the communities, access to market and road. The villages were Gumu-Abush, Sherkole, Tumet and Tsore-almetema from Homosha and Bambasi 02, Mutsa 01, Shebora and Womba-selama from Bambasi.

Determination of breeding objective traits and selection criteria

Two approaches, production system study (Oumer et al. 2019) and phenotypic ranking experiments (Oumer et al. 2021), were used to determine breeding objective traits for the two indigenous goat populations. Based on results from the two approaches, three measurable breeding objective traits were selected for each population. The traits were as follows: (i) body size, twinning ability and kidding interval (KI) in Arab; and (ii) body size, twinning and mothering abilities in Oromo goat population. Some of the traits such as coat colour and beauty which had higher preference by goat keepers were intentionally excluded to avoid the complexity during implementation. Since animals may be selected independently for desired coat colour and beauty, it is not worthwhile to include them in simulations. The selection criteria were six-month weight (6mw), litter size at birth (LSB), litter size at weaning (LSW) and KI for body size, twinning ability, mothering ability and reproduction performance, respectively.

Selection groups

Three selection groups; breeding bucks (BBs), breeding does (BD) and production does (PD), consisting of six selection paths were defined for both populations. Generation and dissemination of genetic gain occur in the breeding unit (BU) and production unit (PU), respectively. The defined selection paths are as follows: (1) bucks to produce breeding bucks (BB

Table 1. Description of the goat populations.

Parameters		Name of the goat populations Arab	 Oromo
Production system		Semi agro-pastoral	Crop-livestock
Agro-ecology		Semi-arid	Sub-humid
Use		Income, meat, saving, wealth status, manure and skin	Income, meat, saving, wealth status, manure and skin
Mating system		Predominantly uncontrolled	Predominantly uncontrolled
Dominant coat colour		Plain white	Plain brown (deep and light)
Coat colour pattern		Plain and patchy	plain, patchy and spotted
Facial profile		Slightly concave	Straight
Horn		Most horned	Most horned
Ear		Droopy	Lateral
Measurements[a]	Body weight	31.7 kg	37.0 kg
	Chest girth	71.1 cm	77.0 cm
	Body length	61.6 cm	69.5 cm
	Wither height	66.7 cm	72.2 cm
	Rump height	69.3 cm	74.0 cm

[a] Measurements were taken from adult female goats.

> BB) where buck selection occurs to improve bucks used in the BU, (2) bucks to produce breeding does (BB > BD) where buck selection occurs to improve does used in the BU, (3) does to produce breeding bucks (BD > BB) where doe selection occurs to improve bucks used in the BU, (4) does to produce breeding does (BD > BD) where doe selection occurs to improve does used in the BU, (5) bucks to produce breeding does (BB > PD) where buck selection occurs to improve does used in the PU, and (6) does to produce breeding does (PD > PD) where does selection occurs to improve does used in the PU. Transmission of genetic gain to the PU is only through the selection group (BB > PD). The selection groups and the gene flow pathways are summarized below in Table 2. Genetic gain is generally expected from selection groups originating from the breeding unit where selection decisions are made and breeding costs are incurred (Nitter et al. 1994). The contribution from the other selection groups in terms of genetic gain is very minimal only through the 5% replacement young does.

Simulation methods

The computer program ZPLAN (Willam et al. 2008) was used to simulate the alternative breeding programs. This computer program is based on comprehensive evaluation of both genetic and economic efficiencies of breeding strategies considering one cycle of selection. Important outcomes of ZPLAN include annual monetary genetic gain (AMGG) for the aggregate genotype, annual genetic gain for individual trait, discounted return and discounted profit for a given investment period. The gene flow method (Hill 1974; McClintock and Cunningham 1974) and selection index procedure constitute the core of the program. For the selection index part, information available for the evaluation of an individual candidate have to be defined by the number and type of relatives contributing to the index of an animal, as well as records on individual's own performance (Willam et al. 2002). For further information on ZPLAN, see Nitter et al. (1994).

During the simulation, we first defined and evaluated a breeding scheme considering ten percent selection proportion and two time unit of buck use for breeding. Then alternative breeding schemes with regard to variation of these two factors (either 2 or 3 years of buck use for breeding and either 10% or 15% selection proportion) were run and evaluated. Thus, the following four alternative schemes were simulated: (1) Scheme 1 (SCM1): 2 years of buck use and 10% selection proportion, (2) Scheme 2 (SCM2): 2 years of buck use and 15% selection proportion, (3) Scheme 3 (SCM3): 3 years of buck use and 10% selection proportion and (4) Scheme 4 (SCM4): 3 years of buck use and 15% selection proportion.

Table 2. Selection groups and the gene flow pathways.

		Genes from		
		Bucks in BU[a] (BB)	Does in BU (BD)	Does in PU[b] (PD)
Genes to	Bucks in BU (BB)	BB > BB	BD > BB	–
	Does in BU (BD)	BB > BD	BD > BD	–
	Does in PU (PD)	BB > PD	–	PD > PD

[a] BU = breeding unit.
[b] PU = production unit.

Input parameters

Essential input parameters for the simulations are given in Table 3. In calculating the numbers of initial does, the flocks from 60 households with an average of 7 BD per household were considered as one breeding unit for Arab goats, while the flocks from 60 households with an average of 6 BD per household were considered as one breeding unit for Oromo goats. Numbers of candidate males were calculated as the product of initial does, conception rate, twinning rate, number of parturition per year, survival rate to six month, kidding rate and sex ratio.

The period for which BD and bucks remain in the flock were adopted from previous study on indigenous sheep breeds in Ethiopia (Mirkena et al. 2012) whereas conception rate, kidding rate and kid survival to six month of age were based on published literature. The KI and LSB were obtained from monitoring data generated on the two goat populations. The rest biological parameters were derived from production system study and phenotypic ranking experiments done on the two goat populations in their respective study areas (Oumer et al. 2019; Oumer et al. 2021).

Regarding the cost parameters, only costs of additional activities to the normal management practices were considered (Nitter et al. 1994). In the current study, these were enumerator salary, cost of items for animal identification, cost of stationary materials and cost of drugs. The costs were computed as of late March 2019 (1 EURO = 1.1374 USD, 1 USD = 28.8439 Ethiopian birr and 1 EURO = 32.8070 Ethiopian birr) when all the information were gathered and compiled from the study areas. Analogous to Jembere et al. (2019) but contrary to Mirkena et al. (2012) and Abegaz et al. (2014), we assumed higher interest rate of discounted returns than costs as such

Table 3. Input parameters by goat populations.

Parameters	Arab	Oromo
Population parameters		
Initial does (IND)	420	360
Number of candidate males/year	217	164
Proportion of bucks selected	0.10; 0.15	0.10; 0.15
Biological parameters		
Breeding doe in use (year)	5	5
Breeding buck in use (year)	2; 3	2; 3
Mean age of does at birth of 1st offspring (year)	1.20	1.30
Mean age of bucks at birth of 1st offspring (year)	1.10	1.20
Conception rate	0.90	0.90
Kidding rate	0.85	0.85
Litter size at birth	1.22	1.11
Kidding interval (KI) (year)	0.81	0.84
Kid survival to six month of age	0.90	0.90
Cost parameters		
Enumerator cost for recording/doe/year (€)	0.94	0.91
Animal identification/doe/year (€)	1.64	1.55
Stationary materials for recording/doe/year (€)	0.13	0.15
Drug/doe/year (€)	1.64	1.55
Interest rate of discounted return (%)	8	8
Interest rate of discounted cost (%)	5	5
Investment period/year	15	15

assumptions lead to more conservative discounted profit (Ehret et al. 2012).

The phenotypic standard deviations and economic weights of breeding objective traits used in the simulations are given in Table 4. The phenotypic standard deviations were obtained from the respective data generated on the two goat populations. Economic weight for each trait was computed using indices from goat keepers' trait preference (i.e. from production system studies). Indices of the selected breeding objective traits were scaled to unity and inversely weighted by additive genetic standard deviation (σ_a) of each trait. Similar approach has been recommended by FAO (2010, p. 73) when only few socio-economic data are available as in the present case. Genetic and phenotypic correlations among the breeding objective traits and their heritability values are presented in Table 5. Genetic parameters are lacking for Arab and Oromo goat populations. Hence, published reports on goats (Abegaz et al. 2014; Jembere et al. 2017) and sheep (Mirkena et al. 2012) were consulted to estimate these parameters. Investigation of genetic and phenotypic correlation between traits could allow for optimal sound selection criteria to match the targeted breeding objectives and yield higher selection accuracies (Wasike et al. 2007).

Results

Predicted annual genetic gains in breeding objective traits

Table 6 presents the predicted annual genetic gain (PAGG) for 6mw (kg) and LSB for the two populations, PAGG for KI (days) for Arab goats and PAGG for LSW for Oromo goats. When the four alternative breeding schemes in both populations were considered, 6mw (kg), the major selection criterion in this study, had the highest PAGG that is quite substantial for an on-farm situation. The PAGG for 6mw, if realized, will result in 288–322 and 342–382 g per year in Arab and Oromo flocks, respectively. In other words, there would be around 34.4 g difference in 6mw for Arab goat population between the alternative with highest gain and the alternative with the lowest gain. The difference was, however, around 39.5 g for Oromo goat population. The PAGG for KI ranged from 0.63 days (SCM3) to 0.70 days (SCM2) for Arab goat. SCM3 improved KI of Arab goat better than any other scheme. The PAGG for LSB in both goats and LSW in Oromo goats were considerably small regardless of the different breeding schemes. In general, for most selection criteria and both populations considered, the PAGG was highest at SCM2 (2 years of buck use and 15% selection proportion) and lowest at SCM3 (3 years of buck use and 10% selection proportion). This was expected as SCM2 benefited from the higher selection intensity and shorter generation interval (Table 7) contributed from strong selection pressure and use of BBs for short durations.

Table 4. Phenotypic standard deviations (σ_p) and economic weights (EWs) for selection criteria by goat populations.

Goat populations	Traits	Unit	σ_p	EW	σ_a
Arab	6mw	Kg	2.01	0.57	1.06
	LSB	№	0.41	4.0	0.09
	KI	Day	35.06	0.004	10.52
Oromo	6mw	Kg	2.41	0.27	1.28
	LSB	№	0.32	3.00	0.11
	LSW	№	0.36	3.67	0.09

Note: 6mw = six-month weight; LSB = litter size at birth; KI = kidding interval and LSW = litter size at weaning.

Table 5. Genetic correlation (above diagonal), heritability (along diagonal) and phenotypic correlation (below diagonal) for selection criteria in two goat populations.

	Arab				Oromo		
Selection criteria	6mw	LSB	KI		6mw	LSB	LSW
6mw	0.28	0.00	0.10	6mw	0.28	0.00	0.30
LSB	0.00	0.15	0.61	LSB	0.00	0.15	−0.20
KI	0.50	−0.06	0.09	LSW	0.10	0.15	0.05

Note: 6mw = six-month weight; LSB = litter size at birth; KI = kidding interval and LSW = litter size at weaning.

Table 6. Predicted annual genetic gains (PAGG) for the breeding objective traits in different schemes of selection.

		Scheme			
Goat population	Trait	SCM1	SCM2	SCM3	SCM4
Arab	6mw	0.3077	0.3222	0.2878	0.2990
	LSB	0.0067	0.0070	0.0062	0.0065
	KI	0.6731	0.7048	0.6296	0.6542
Oromo	6mw	0.3627	0.3816	0.3421	0.3577
	LSB	0.0023	0.0025	0.0022	0.0023
	LSW	0.0069	0.0073	0.0066	0.0068

Note: 6mw = PAGG in six-month weight (kg); LSB = PAGG in litter size at birth; KI = PAGG in kidding interval (days); LSW = PAGG in litter size at weaning.

Monetary genetic gain and predicted discounted returns

The AMGG, discounted returns, discounted profits, generation intervals and selection intensities from the four alternative breeding schemes for the two populations are presented in Table 7. The AMGG (Euro/doe) ranged from 0.19 (SCM3) to 0.21 (SCM2) for Arab goat and from 0.12 (SCM3) to 0.14 (SCM2) for Oromo goat; where the AMGG from SCM1 was similar to that of SCM4. The discounted profit, calculated as the difference between the discounted return and discounted cost per doe, obtained in all the alternatives and in both populations was substantial. However, the discounted profit obtained in this study must be seen with caution as economic weight attached to each trait is not in the real monitoring term

Table 7. Annual monetary genetic gain (AMGG), discounted costs (cost), discounted returns (return), and discounted profit (profit) in Euro from the four schemes (SCM) for Arab and Oromo goat populations.

		Scheme			
Goat population	Parameter[a]	SCM1	SCM2	SCM3	SCM4
Arab ($r_{TI = 0.435}$)	AMGG	0.20	0.21	0.19	0.20
	Return	1.09	1.15	0.99	1.04
	Profit	0.85	0.91	0.75	0.80
	Generation interval	2.58	2.58	2.89	2.89
	Selection intensity	1.23	1.30	1.30	1.36
Oromo ($r_{TI = 0.434}$)	AMGG	0.13	0.14	0.12	0.13
	Return	0.65	0.70	0.60	0.63
	Profit	0.42	0.46	0.37	0.40
	Generation interval	2.67	2.67	2.98	2.98
	Selection intensity	1.20	1.27	1.27	1.34

[a] Breeding costs were per doe and in EURO.

and only additional costs to the normal management practice were considered as the cost parameters. Hence, it may not be appropriate to compare the alternative breeding schemes in this study based on the discounted profit. As mentioned previously, economic weight for each trait was computed using indices from goat keepers' trait preference (i.e. production system studies). For the two populations, the accuracies of selection (r_{TI}) were moderate and the generation intervals and selection intensities obtained from the alternative breeding schemes were within the ranges of 2.58–2.98 years and 1.20–1.36, respectively.

Discussion

Genetic responses of indigenous Ethiopian goat breeds under selective breeding programs have not been well studied. Indeed, Abegaz et al. (2014) optimized alternative breeding schemes for two Ethiopian goat breeds. The authors reported PAGG for 6mw (kg) that ranged from 0.36 to 0.37 for Abergelle goat and this was comparable with the magnitude of the present result. On the contrary, the authors presented higher PAGG for 6mw, which varied from 0.870 to 0.872 kg, for Western Lowland goat. Jembere et al. (2019) also evaluated genetic and economic responses of alternative breeding schemes for three indigenous goat breeds of Ethiopia and found relatively lower PAGG for 6mw (kg) that ranged between 0.09–0.25, 0.13–0.47 and 0.10–0.27 for Abergelle, Central Highland and Woyto-Guji goat breeds, respectively.

Except Abegaz et al. (2014) and Jembere et al. (2019), literature reports on similar breeding schemes are generally lacking on indigenous goat breeds of Ethiopia. Nevertheless, there are reports available on sheep breeds in Ethiopia and elsewhere. For instance, Dagnew et al. (2018) reported PAGG of 0.15–0.34 kg for yearling weights of Gumuz sheep which concurs well with the current study though the species are different. Similarly, Mirkena et al. (2012) simulated breeding programs for indigenous sheep breeds of Ethiopia and found much higher PAGG for yearling weights in kg of 0.81–0.89 for Bonga, 0.85–0.94 for Horro and 0.62–0.70 for Menz. The results from Mirkena et al. (2012) were indeed challenged by the recent findings of Haile et al. (2020) who analyzed 10-year (2009–2018) performance data from the same sheep breeds: Bonga, Horro and Menz. They found an annual average genetic gain for 6mw (kg) of 0.21, 0.18 and 0.11 in the same order of the three breeds. This implies that the values reported by Mirkena et al. (2012) are too high and hence it is less realistic to achieve these much gains under on-farm condition. On the other hand, PAGG of 0.12–0.29 kg for 6mw of Menz sheep was reported by Gizaw et al. (2014).

The observed variations between the current results and the findings reported elsewhere are probably related to the difference in phenotypic standard deviations and selection intensity used during the simulations. For example, in this study, phenotypic standard deviations used for 6mw were 2.01 and 2.41 kg for Arab and Oromo goat populations, respectively. However, Abegaz et al. (2014) reported relatively higher phenotypic standard deviations, 2.74 kg for Abergelle and 3.76 kg for Western Lowland goat. Similarly, Mirkena et al. (2012) reported higher phenotypic standard deviations of 6.36 kg for Bonga and Horro breeds and 3.49 kg for Menz. Conversely, Jembere et al. (2019) used lower phenotypic standard deviations of 2.09, 2.22–3.90 and 2.29 kg for Abergelle, Central Highland and Woyto-Guji goats, respectively. The PAGG for a trait is directly proportional to the phenotypic standard deviation.

LSB, defined as the number of kids born/doe/kidding, is strongly influenced by management decisions and are of paramount economic importance. Given the low heritability of the trait, the PAGG in LSB for Gumuz sheep were within the range of 0.0017–0.0036 (Dagnew et al. 2018) and for Menz sheep it fluctuated from 0.0013 to 0.0031 (Gizaw et al. 2014), and hence, were equivalent to the values presented in the present work. Similarly, comparable results were also reported by Mirkena et al. (2012), Abegaz et al. (2014) and Jembere et al. (2019).

Regarding LSW, the number of kids weaned per doe per year, our PAGG for this selection criterion were very low and concurred well with the findings of various scholars elsewhere in Ethiopia (Mirkena et al. 2012; Abegaz et al. 2014; Jembere et al. 2019). Overall, the PAGG in both LSB and LSW may appear very insignificant; yet, the slightest improvements in these cumulative traits would lead to sizable gain in terms of overall change.

KI, calculated as the difference in days between two successive kiddings, had positive gain in the four alternative breeding schemes. However, the positive gain for KI is undesirable as an increase in KI implies an addition in the number of days between consecutive kidding. An Arab doe with long KI will have lower chances of giving more number of kids during her lifetime. Jembere et al. (2019) also reported positive PAGG for KI that ranged from 0.18 to 0.27 days.

Conclusion

Different breeding schemes were simulated for two indigenous goat populations of Ethiopia, considering limited number of breeding objective traits. The PAGGs obtained from all schemes were reasonable, especially for 6mw in both populations and KI in Arab goat. The PAGGs in LSB and LSW were small implying that improvements of these traits are best achieved through improved management issues such as health and feeds as part of the overall genetic improvement program. Based on the results of the present study, design and implementation of the CBBP for Arab and Oromo goat populations using SCM2 had an advantage over other schemes.

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