Original article

Thermodynamic life cycle assessment of humans with considering food habits and energy intake

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A R T I C L E   I N F O

A B S T R A C T

All biotic species, including humans, requires energy for their survival and obtained from the process of metabolism. Present work deals with the thermodynamic analysis of the metabolic process of humans and establishes the relation for entropy generation. Further, this entropy generation is linked with the thermodynamics life cycle assessment of humans. Data used in this work is provided by the National sample survey office (NSSO), Government of India. Entropy generation is determined on the bases of per kg of carbohydrate, palmitic acid and 20 amino acids. Finally, the life span of humans has been determined on the grounds of the entropy generation. Entropy generated by Haryana people is maximum in all states, and Tamilnadu people have the minimum among all the states. Total entropy production for Haryana is 23.59 kJ/K-kg-food and for Tamilnadu 19.71 kJ/K-kg-food. People living in Haryana has a life span of 66 years, and Tamilnadu people have a life span of 79 years. The life span for other states ranging in 66–79 years. Variation of ±3% is recorded in the life span of people when compared with the NITI Aayog report. There is a minor difference of 1.22 years in case of life expectancy of Kerla when compared to the NITI Aayog report. In current research work effect of water and air, inhalation is not considered. So one can think these parameters and analyze the variation of the result.

1. Introduction

From the last few decades, classical thermodynamics is used to develop a fundamental understanding of the biological systems. The exchange of mass, momentum, and energy are all obeyed by natural methods. The second law of thermodynamics is essential to understand the phenomena of evolution, growth, ageing, and death. The field of biological thermodynamics covers not only living plants and animals but also societies and corporations. To understand the growth, ageing and end of the natural system, one should know about entropy. Entropy can be evaluated for living and non-living systems both. Ibrahim Dincer (2001) studied the concept of energy, exergy and entropy for all the thermodynamic system, and these concepts are equally applicable for living

and non-living systems. Prigogine (1961) consider the biological system as an open thermodynamic system and explain the dynamics of living organisms. He has described the many internal variables inside the natural species and their relation with the surrounding environment. Zotin and Pokrovskii (2018) investigated the growth and development of biological species in terms of various thermodynamic parameters. Silva Carlos (2008) investigated the entropy production in males, females, and children. According to his investigation, entropy production in males is more than female. The methodology adopted by him applies to all species if the growth chart, energy consumption and diet composition are known. He has calculated the life span for males and females on the bases of physical activity level (PAL) and concluded that a person with light exercise has the highest lifespan and with intense exercise has a minimum lifecycle. Ichiro (1989) Studied the entropy inflow and outflow from the human body in a naked position under the basal condition in the respiration calorimeter due to different modes of heat and mass transfer. His analysis is based on the data obtained by Hardy D. James. Aoki concluded that entropy production from the human body is nearly constant in the temperature range of 26–32 °C. Rahman (2007) determined the entropy production from the human body by considering entropy flux to and from the human body. He has also considered the heat

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loss due to convection to and from the human body and physical activity level (rest and intense exercise). He has calculated the entropy production at rest, training and death are 21×10^{-5} kW/K, 219×10^{-5} kW/K and zero kW/K respectively. K. Annamalai (2002) analyzed the human body thermodynamically and determined the entropy production 10000 kJ/kg K per person and predicted the life span 77 years. Kuddusi H. et al. (Kuddusi, 2011) studied glucose oxidation in the human body and its consumption. Entropy production due to glucose oxidation is computed as 0.41×10^{-5} kW/kg K and predicted the life span of 77.34 years. James Hardy et al. calculated the heat loss from the human body on the bases of hardy radiometer and respiration calorimeter. In this work, the purely thermal loss was considered. A man in the dressed and undressed situation was put inside the calorimeter and losses are calculated. In hardy work rectal temperature and skin temperature also measured. Ichiro Aokienti studied the entropy production of various age groups in human, and it is evident that entropy production in 0–2 years of age increases rapidly between 3 and 25 years of age, it decreases and after that rate of decrement is prolonged and become zero at death. In his, work Aoki considers that entropy production during pregnancy is zero, but that is not true; after the fertilization of the egg, many chemical reactions take place. Hence entropy production during pregnancy ideally should not be zero. Aoki investigated the entropy production in the human body during the exercise and chilling condition and compared it with normal basal conditions and concluded that entropy production during light exercise is 1.5–2.4 times compared to the basal state. During heavy physical activity, the entropy production is almost six times from normal basal conditions. Aoki also studied the effect of the chilling environment on entropy production and found that during chilling conditions, human muscles get contracted; thus, heat production increases and so entropy production also increases. Peter Lenart et al. tries to connect the missing link between entropy generation and ageing with the help of a mathematical model. In this model, he has linked the heat stress model with ageing and predicts that if entropy increase, then it leads to the formation of double strands breaks which ultimately results in ageing phenotype. Melek Ece Ongel et al. determined the entropic age of women on the bases of telomere length and diet. He has concluded that if telomere length is short, then life span will be less and also find that this telomere length is more in women as compared to men. Abdullah S. Alhomida in his book discussed the diabetic renopathy, which is mainly caused due to diabetes. In his book chapter, he has also suggested how one can reduce the risk of diabetes by doing physical exercise and controlling diets. In another work, Abdullah S. Alhomida investigated the impact of neurodegeneration and neuroprotection in diabetic retinopathy.

Kuddusi Lutfullah has calculated the entropy production for humans on the bases of the food habit of people living in Turkey. He has applied the law of thermodynamics to determine entropy production. Foods mainly comprised of fat, protein, and carbohydrate and metabolized with the help of oxygen, and this food is transformed into energy. The author considered the human body as a heat engine, and efficiency of the human body is around 25–30% Silva C, and Annamalai K. et al. determine the entropy production from men and women with considering the food data obtained from the USFDA. The author has found the average lifetime entropy production is 11404 kJ/kg K. On the bases of the above data, they have predicted the life span for men and women is 73.78 and 81.61 years, respectively. Hershey D, 1980 consider the rest condition for men and women both and find the entropy production 10025 kJ/kg K and 10678 kJ/kg K for men and women, respectively. Abhijit et al. (2019) computed the entropy production from human lung, and the effect of various parameters such as absolute humidity, relative humidity, and the atmospheric temperature had been assessed. Dutta has also investigated the impact of the Lewis number on entropy production due to heating and humidification. Ichiro Akoi published a book Ichiro (2012) in 2012 and applied the various laws of thermodynamics to calculate the energy and entropy production rate in biotic and abiotic species. In chapters 1 and 3 of this book, he discussed the general entropy principle and entropy production rate from animals. In chapters 4 and 5 of the book, he discussed the direct and indirect approach for the calculation of entropy production rate through calorimetric. According to his discussion human, have maximum, and minimum entropy production rate in his life span, and entropy production rate approaches towards zero at the time of death. Hershey D. et al. states that death occurs due to maximum disorder in various organs, and this leads to maximum entropy generation at the time of death. Here author clears that entropy production rate per unit mass is minimum, not the total entropy production. Boregowda C. Satish et al. studied the impact of thermal stress on the human body entropy production with the help of the finite element method. He has validated the various parameters like the effect of age, air temperature, relative humidity and physical activity in entropy production. Dutta Abhijit et al. investigated the effect of age and gender on the human respiratory system. He has observed the exergy transfer per day is maximum during the workout than breathing process. In another work, he has computed the entropy production on the bases of Hess-Murray theory and Weibull experiment. Here he has considered one is rest and other is heavy physical exercise. Entropy production at the rest condition is more in case of the Weibull model. In new work, Dutta Abhijit has investigated the performance of the cardiorespiratory system of the human body to judge the impact of physical activity level and other environmental parameters. On the bases of the above work, he has concluded that the performance of the cardiorespiratory system increases with an increase in physical activity level. He also checked the effect of breath to heart ratio (BHR) on the efficiency of the cardiopulmonary system.

From the above literature, the researcher has concluded that many authors have attempted the entropy generation in humans. Entropy production has been computed for resting conditions, mild exercise, and heavy exercise through the indirect calorimetric system. Some authors also computed the entropy production from the individual human organs such as lungs and heart. Few authors have calculated the entropy production on the bases of carbohydrate, fat and protein. Still, none has determined the entropy production and life cycle in the context for the Indian subcontinent. In this work, the entropy production and life span of humans residing in the urban community of India has been computed and compared with life expectancy data of NITI Aayog in INDIA.

2. Problem identification

Humans consumed a variety of food, which is composed of protein, fat, and carbohydrate. Every meal contains these parameters in different quantities. Carbohydrate, Fat, and Protein are formed from glucose, palmitic acid and 20 types of amino acid. With the help of air and oxygen, these substances are chemically metabolized and produce heat and work for the functioning of the human body. Food consumed by humans can produce heat and work. Work does not have entropy, but heats do. Production and dissipation of heat is an irreversible process, so with the temperature is a function of heat, entropy can be determined. Fig. 1(b) shows the schematic presentation of the entire work plan of this research. Foods are consumed at 25 °C (atmospheric temperature), and it is metabolized at 37 °C (core temperature). after metabolism heat is generated and this heat is the leading cause of entropy generation.
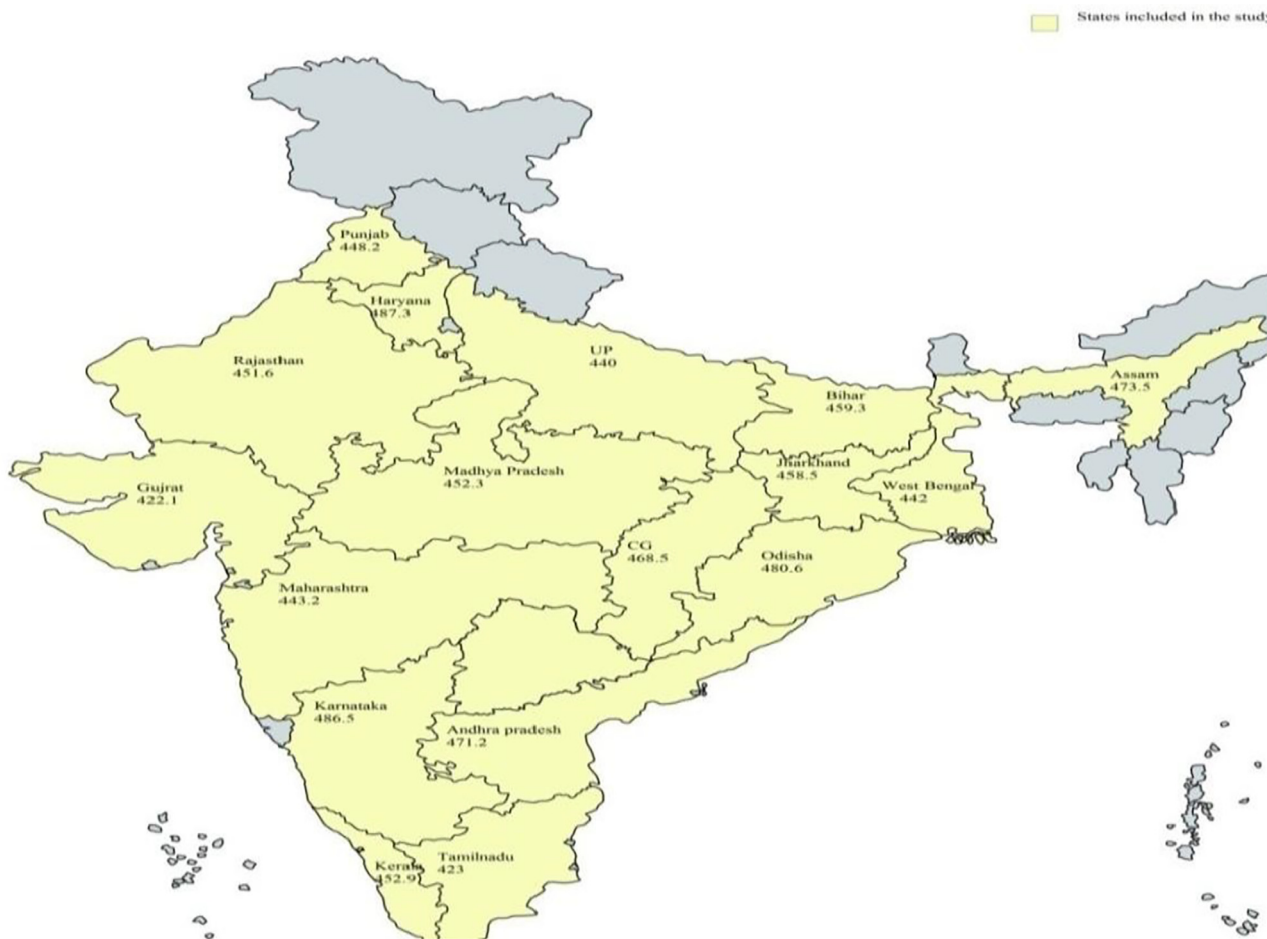
Fig. 1a. (a). Total Intake of Protein, fat, and carbohydrate (in grams) per person per day in Indian states (www.nin.res.in).
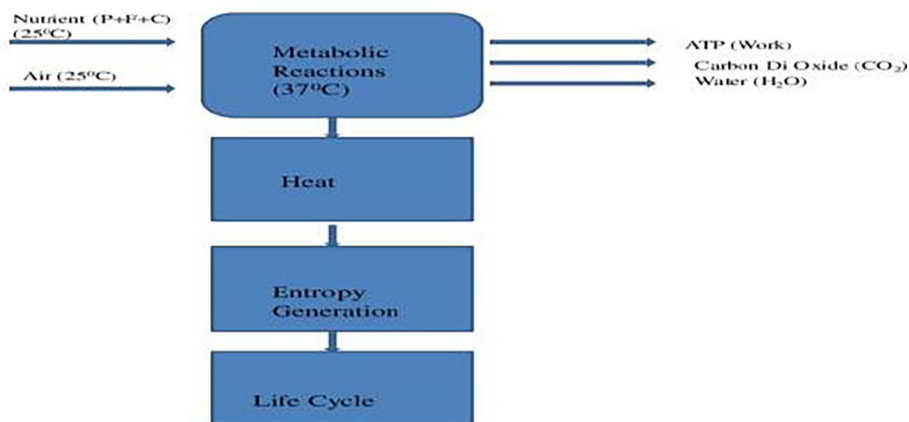

Fig. 1b. (b) Schematic diagram of the methodology followed.

Production of entropy due to food habits and energy intake is a unique problem which is chosen by the author to calculate the entropy production from homeotherms, and the author also calculates the entropy production rate per unit mass and total entropy production in entire life. The reason behind this study is that India is a very diversified country in culture as well as food habits. On the bases of the entropy production, the author has predicted the life span for Indian people's livings in various regions. In the present study, energy intake data of 17 major Indian states has been

used to calculate the entropy production. Hilly area states are not included in the study. Life span obtained from entropy production is compared with the life expectancy data of NITI Aayog, which has not happened before and not found in the literature.

3. Data collection

Various food and energy-related data are collected from a report "NUTRITIONAL INTAKE IN INDIA" (Nelson and Cox, 2003)

Published by National Sample Survey Office (NSSO) New Delhi is shown in Table 1 This food-related data is obtained from door to door surveys done by NSSO.

This data is available on the bases of the Urban and rural areas and the Indian States wise. In this work, only urban area data has been considered. India is regarded as a much-diversified country, and sources of protein, fat, and carbohydrate are varying according to the location and climate of the state. For example, states like Punjab and Haryana are taking most of the protein and fat form Dairy products and southern states like Tamilnadu, Kerala and Karnataka are getting a significant portion of protein and fat from Non-veg foods like chicken, egg and meat. For other data such as oxygen(O_2) Intake and Carbon dioxide (Co_2) exhale taken from the research work of Hardy and DU Bois. In this work, water intake is not considered because water is not containing protein, fat, and carbohydrate. With the help of Fig. 1(a), the total amount of protein, fat, and carbohydrate consumed are shown states wise. Data for the Telangana state is included in Andhra Pradesh because Telangana is not bifurcated at the time of the survey. Here the portion of protein, fat, and carbohydrate are mention in Table 1 states wise. Quantity of cooked food intake by the human in kg/day has opted from a report published by the National Institute of Nutrition, Hyderabad. According to the report, a human consumes 1.25 kg/day of cooked food on an average. Mass of the human is considered as 62 kg on as average in this work.

4. Methodology adopted

Laws of thermodynamics are equally applicable for both living and non-living things. In present work laws of thermodynamics is applied for the humans and estimating the performance of the human body in terms of entropy production and life cycle analysis.

4.1. First law of thermodynamics for human body

first law of the thermodynamic state that the change in enthalpy of a system equals the net heat transfer into the system minus the net work done by the system. Human body metabolism is a typical example of an open thermodynamic system where heat is generated and transfer to the environment by keeping the inner

Table 1
Average Calorie Intake and Protein, fat and carbohydrate values state wise (Nelson and Cox, 2003).

S. No.	State	Energy Intake (Kcal) Per day per capita	Protein Intake in gm	Fat intake in gm	Carbohydrate intake in gm
1	Andhra Pradesh	2281	59.3	55.2	356.7
2	Assam	2110	54.9	39.2	379.4
3	Bihar	2170	60.9	42.5	355.9
4	Chhattisgarh	2205	55.8	42.2	370.5
5	Gujarat	2154	56.3	73.1	292.7
6	Haryana	2443	68.6	74.7	344.0
7	Jharkhand	2175	60.3	44.2	354.0
8	Karnataka	2245	59.1	59.8	367.6
9	Kerala	2198	62.7	54.6	333.9
10	Madhya Pradesh	2209	63.1	55.9	333.3
11	Maharashtra	2227	61.2	66.8	315.2
12	Odisha	2191	55.9	37.7	387.0
13	Punjab	2299	64.9	69.2	314.1
14	Rajasthan	2320	66.7	70.7	314.2
15	Tamilnadu	2112	55.7	52.0	315.3
16	Uttar Pradesh	2144	61.1	52.8	326.1
17	West Bengal	2130	57.9	48.4	335.7
18	**INDIA**	**2206**	**60.3**	**58.0**	**323.2**

body temperature remains constant. The first law of thermodynamics for the open system shown as:

$$Q = H - W \tag{1}$$

$$Q = H_p - H_r \tag{2}$$

where Q is the Heat, H is the Enthalpy, and W is the Work. Here it is assumed that the one molecule of glucose, palmitic acid, and 20 amino acids are considered in the above reactions. A human body is supposed to be an open system, and all the reactions take place at constant volume, so the amount of work transfer is not involved, and Eq. (1) is reduced to Eq. (2), here H_p and H_r is the enthalpy of product and reactant. Eq. (2) is further written as
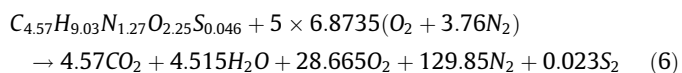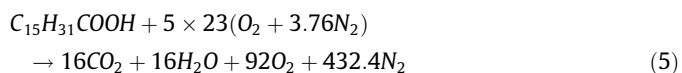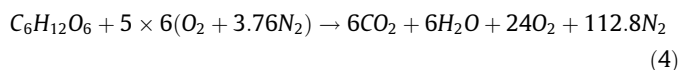
$$Q = \sum n_p(h_f^{-0} + h^- - h^{-0})p - \sum n_r(h_f^{-0} + h^- - h^{-0}) \tag{3}$$

where

n_p = mole no. of products

n_r = mole no. of reactants

h_f^{-0} = enthalpy of formation at the reference temperature

h^- = reaction temperature enthalpy

h^{-0} = reference condition enthalpy

It is supposed that food is consumed at 25 °C (reference temperature), and the metabolic reaction of food occurs at 37 °C (reaction temperature).

The air around a human is rich with oxygen. A reaction may occur with the minimum amount of air needed for complete combustion of a fuel. The reactions in a healthful human occur with 400% Excess Air. The complete reactions of glucose, palmitic acid and the average of 20 amino acids with 400% Excess Air are shown in Eqs. (4)–(6). In the thermodynamic system, the human body is considered an open system. Human metabolism is the conversion of food into heat, work, and stored in the form of ATP. The surrounding air is rich in oxygen, nitrogen and carbon dioxide and a reaction in the presence of these components is required to complete the combustion of food. For a healthy human body, 400% of excess air is necessary for a healthy metabolism process. Eqs. (4)–(6) shows the complete reaction of carbohydrates (glucose), fat (palmitic acid) and Protein (Amino acids) with 400% air. These equations are referred to from (Annamalai, 2002).

$$C_6H_{12}O_6 + 5 \times 6(O_2 + 3.76N_2) \rightarrow 6CO_2 + 6H_2O + 24O_2 + 112.8N_2 \tag{4}$$

$$C_{15}H_{31}COOH + 5 \times 23(O_2 + 3.76N_2)$$
$$\rightarrow 16CO_2 + 16H_2O + 92O_2 + 432.4N_2 \tag{5}$$

$$C_{4.57}H_{9.03}N_{1.27}O_{2.25}S_{0.046} + 5 \times 6.8735(O_2 + 3.76N_2)$$
$$\rightarrow 4.57CO_2 + 4.515H_2O + 28.665O_2 + 129.85N_2 + 0.023S_2 \tag{6}$$

There is no sulfur content in fat and carbohydrate, but a little percentage of sulfur is present in amino acids. From literature, it is found that the temperature required for the reaction of sulfur with air is around 100–120 °C, and the human body temperature is not high enough to react. So the reaction of sulfur with amino acids is not considered in this work. If sulfur is reacted with oxygen, then it will produce sulfur dioxide, which is not suitable for the environment and the leading cause of acid rain. In the said equations, it is supposed that carbon and hydrogen are get converted into CO_2 and H_2O. All actions are exothermic in the manner and release heat. Values of enthalpies of glucose, palmitic acid and 20 amino acids are shown in Table 2. Enthalpies of oxygen, nitrogen, water, and carbon dioxide are also demonstrated in Table 2 at the reference temperature and reaction temperature.

Table 2
. Enthalpies values are products and reactants.

Substance	Formation enthalpy h_f^{-0} (kJ/kmol)	Reference temperature enthalpy (25 °C) (kJ/kmol)(h^{-0})	Reaction temperature enthalpy (37 °C) (kJ/kmol)(h^{-})
$C_6H_{12}O_6$	−1260000	–	–
$C_{15}H_{31}COOH$	−835000	–	–
$C_{4.57}H_{9.03}N_{1.27}O_{2.25}S_{0.046}$	−385000	–	–
O_2	0	8682	9030
N_2	0	8669	9014
H_2O(gas)	−241820	9904	10,302
CO_2	−393520	9364	9807

From Eq. (3) and Table 2, one can calculate the value of heat liberated due to the combustion of glucose, palmitic acid, 20 types of amino acid. These are not the value of heat released from the human body, because the human body produced heat as well as ATP molecule and the ATP molecule is considered as work in terms of thermodynamics. These are values of heat released from combustion in a calorimetric device.

$Q_{glucose}$ = −2499726 kJ/kmol
$Q_{palmiticacid}$ = −9135790 kJ/kmol
$Q_{20aminoacids}$ = −2446606 kJ/kmol

4.2. Metabolic efficiency

Metabolic efficiency is defined as a parameter up to which human body fuel (carbohydrate, fat, and protein) is utilized for better functioning of human body parts. In other words, it is also treated as work obtained from the ATP molecule.

$$\text{Metabolic efficiency of human} = \frac{W_{ATP}}{Q}$$
$$= \frac{work \; from \; ATP \; molecule}{total \; heat \; production}$$

Silva and Annamalai in his work provide the metabolic efficiency of carbohydrates, fat, and amino acids.

Substance	Metabolic efficiency in per cent
$C_6H_{12}O_6$	34.6
$C_{15}H_{31}COOH$	32.2
$C_{4.57}H_{9.03}N_{1.27}O_{2.25}S_{0.046}$	10.4

In the thermodynamics process, entropy transfer only occurs with heat exchange, so here work transfer from the human body is not considered. The heat transfer from the human body can be estimated with the help of metabolic efficiency.

The heat liberated due to the combustion of glucose, palmitic acid, and amino acid is the leading cause of entropy production and can be computed as:

$$Q_{sglucose} = (1 - \eta_g) \times Q = (1 - 0.346)(-2499726)$$
$$= -1634820.80 \; \text{kJ/kmol} \tag{7}$$

$$Q_{spalmeticacid} = (1 - \eta_{pa}) \times Q = (1 - 0.322)(-9135790)$$
$$= -6194065.62 \; \text{kJ/kmol} \tag{8}$$

$$Q_{s20aminoacid} = (1 - \eta_{20aa}) \times Q = (1 - 0.104)(-2446606.30)$$
$$= -2192159.25 \; \text{kJ/kmol} \tag{9}$$

Values are given in Eqs. (7)-(9) are the values heat transfers outside the human body containing all modes of heat transfer. Entropy production occurs at the same time as heat transfer. Here temperature of the human body is taken as 37 °C, and atmospheric temperature is supposed to be 25 °C. Here it is considered that food and air are consumed at atmospheric temperature, and heat rejection is taking place at skin temperature.

4.3 The second law of thermodynamics for the human body

Second law of thermodynamics states that there exists a useful state variable called entropy. Entropy is the measure of a systems thermal energy per unit temperature, which is unavailable for doing useful work. In other words, entropy is the parameter upon which perfectness of a system can be measured. If perfectness of the system is in good order, the efficiency of that system will be maximum. Mathematically entropy is the function of heat and temperature. The second law of thermodynamics for all systems may be written as

$$ds \geq \frac{dQ}{T} \tag{10}$$

$$S_{gen} = dS_{system} + dS_{enviromnent} \tag{11}$$

S_{gen} Here the entropy production of the universe $dS_{system} and dS_{enviromnent}$ is the entropy of the system and environment, which may be positive, negative and zero, depending upon the process. Here one may consider the human body as a system, and can be written as:

$$dS_{system} = S_p - S_r \tag{12}$$

Here $S_p and S_r$ are the entropy of products and reactants. Here entropy change for a system may also be written as in molar form. In a mixture of ideal gases the entropy may also be calculated as:

$$S_i = n_i \bar{S_i}(T, P_i) = n_i \left[\bar{S_i}(T, P_0) - R_u \ln(y_{ni}P) \right] \tag{13}$$

The characters in this equation are
n_i = mole no. of the ith component
S_i = Total entropy of ith component
T = Mixture Temperature
P_i = partial Pressure of ith component
P_0 = Atmospheric Pressure
R_u = Universal Gas constant (8.314 kJ/kmol K)
y_{ni} = Mole fraction of ith component in the mixture
P = Pressure inside the Human Body (1 atm)
Entropy generation from 1 kg of carbohydrate, palmitic acid, and 20 amino acids:

$$S_{g.glucose} = \Delta S_{sys} + \Delta S_{envi} = S_p - S_r + \frac{-Q_{s.glucose}}{T_{envi}} \tag{14}$$

$$= 29884 - 28586 + \frac{-(-1634820)}{310} = 6573 \text{ kJ/(K kmol glucose)}$$
Molar mass of glucose = 180 kg/kmol Glucose

$$S_{g.glucose} = \frac{6573}{180} = 36.51 \text{kJ/(kg K)} \tag{15}$$

By a similar process, entropy production of palmitic acid and 20 amino acid has been calculated.

$$S_{g.palmeticacid} = 86.4 \text{ kJ/(kg K)} \tag{16}$$

$$S_{g.20aminoacid} = 66.8 \text{ kJ/(kg K)} \tag{17}$$

These values of entropy production of glucose, palmitic acid and 20 types of amino acid have been calculated with the help of Tables 3 and equation (13).

Table 3

. values of entropies and combustion of (a) Glucose, (b) palmitic acid and (c) Amino Acids for the human body. (Nelson and Cox, 2003).

(a)For Glucose or Carbohydrate (Nelson and Cox, 2003)

At (298 K)	n_i	y_{ni}	$\bar{S}_i(T,1\ atm)$	$R_u \ln(y_{ni}P)$	$\bar{S}_i$	$n_i \bar{S}_i$
$C_6H_{12}O_6$	1	1	212		212	212
O_2	5×6	0.21	205.04	−12.97	218.01	6540
N_2	5×6×3.76	0.79	191.61	−1.97	193.58	21,834
TOTAL						S_r = 28586
At (310 K)						
CO_2	6	0.0403	213.7	−26.69	240.39	1442.34
H_2O	6	0.0403	188.8	−26.69	215.49	1292.94
O_2	24	0.1613	205	−15.16	220.16	5283.84
N_2	112.8	0.7581	191.54	−2.30	193.84	21865.15
TOTAL	148.8	1				S_p = 29884.27

(b) For Palmitic acid (Nelson and Cox, 2003)

At (298K)	n_i	y_{ni}	$\bar{S}_i(T,1\ atm)$	$R_u \ln(y_{ni}P)$	$\bar{S}_i$	$n_i \bar{S}_i$
$C_{15}H_{31}COOH$	1	1	452.4	0	452.4	452.4
O_2	5×23	0.21	205.04	−12.97	218.02	25072.3
N_2	5×23×3.78	0.79	191.61	−1.95	193.57	83699.66
TOTAL						S_r=109224.3
At (310K)						
CO_2	16	0.028	213.7	−29.72	243.19	3895.84
H_2O	16	0.028	188.8	−29.72	218.29	3492.64
O_2	92	0.165	205	−14.98	219.97	20237.24
N_2	432.4	0.777	191.54	−2.09	193.64	83729.93
TOTAL	556.4	1				S_p= 111355.65

(c)For amino acids (Nelson and Cox, 2003)

At (298K)	n_i	y_{ni}	$\bar{S}_i(T,1\ atm)$	$R_u \ln(y_{ni}P)$	$\bar{S}_i$	$n_i \bar{S}_i$
$C_{4.57}H_{9.03}N_{1.27}O_{2.25}S_{0.046}$	1	1	1.40×119	0	166.6	166.6
O_2	5×6.87	0.21	205	−12.97	218.02	7488.98
N_2	5×6.87 × 3.76	0.79	191.61	−1.95	193.57	25000.72
TOTAL						S_r=32656.30
At (310K)						
CO_2	4.57	0.027	213.7	−29.94	243.64	1113.42
H_2O	4.51	0.026	188.8	−30.06	218.86	987.05
O_2	28.66	0.171	205	−14.68	219.68	6296.02
N_2	129.85	0.774	191.54	−2.12	193.66	25146.75
TOTAL	167.59					S_p=33543.24

(d) Total entropy production, entropy production rate, life span and life Span (NITI Aayog)

S. No.	States	Total entropy production due to protein, fat, and carbohydrate intake (kJ/K-kg-food)	Entropy production rate (kW/K)	Entropy production rate per unit mass (kW/K-kg)	Life span (Years)	Life span in years ((NITI Aayog Report))
1	Andhra Pradesh	21.74	31.3×10^{-5}	0.505×10^{-5}	71.74	68.5
2	Assam	20.89	30.08×10^{-5}	0.485×10^{-5}	74.56	63.9
3	Bihar	20.72	29.84×10^{-5}	0.481×10^{-5}	75.14	68.1
4	Chhattisgarh	20.89	30.08×10^{-5}	0.485×10^{-5}	74.54	64.8
5	Gujrat	20.74	29.86×10^{-5}	0.481×10^{-5}	75.08	68.7
6	Haryana	23.59	33.97×10^{-5}	0.547×10^{-5}	66.00	68.6
7	Jharkhand	20.75	29.89×10^{-5}	0.482×10^{-5}	75.02	66.6
8	Karnataka	22.52	32.43×10^{-5}	0.523×10^{-5}	69.12	68.8
9	Kerala	21.05	30.31×10^{-5}	0.488×10^{-5}	76.12	74.9
10	Madhya Pradesh	21.2	30.05×10^{-5}	0.484×10^{-5}	74.62	64.2
11	Maharashtra	21.35	30.74×10^{-5}	0.495×10^{-5}	72.93	71.6
12	Odisha	21.12	30.41×10^{-5}	0.490×10^{-5}	73.72	65.8
13	Punjab	21.67	31.35×10^{-5}	0.505×10^{-5}	71.60	71.6
14	Rajasthan	22.02	31.71×10^{-5}	0.511×10^{-5}	70.76	67.7
15	Tamilnadu	19.71	28.38×10^{-5}	0.457×10^{-5}	79.00	70.6
16	Uttar Pradesh	20.54	29.58×10^{-5}	0.477×10^{-5}	75.81	64.1
17	West Bengal	20.30	29.23×10^{-5}	0.471×10^{-5}	76.77	70.2
18	**INDIA**	20.83	29.99×10^{-5}	0.483×10^{-5}	74.86	67.9

Eqs. (15), (16), and (17) show that the entropy production inside the human body due to chemical reaction takes place. All these values are in 1 kg of glucose, palmitic acid, and 20 amino acids, respectively. Factors such as water and airflow to and from the system are not impacting the entropy production. So these factors are not included in this work.

5. Result

Entropy production from Human Body due to food Intake: In macroscopic level, when irreversibility is occurring, it reflects in the form of entropy production. In the case of humans, entropy production is mainly taking place due to two factors, i.e. external irreversibility and internal irreversibility. Entropy production due to physical activity like walking, running and doing exercise comes under external irreversibility and entropy production due to the metabolism of food and breathing considered under the internal irreversibility. Internal entropy production is mainly due to the chemical reaction of protein, fat, and carbohydrate take place inside the human body. Entropy production is also affected by the quantity and quality of air inhalation and exhalation. In the current research, work author has determined the entropy production of the human body in the entire life cycle and entropy production rate on the bases of food intake and chemical metabolism of the human body in the presence of atmospheric air. Further, the life span of human for Indian states has been determined and compared with the life expectancy data of NITI Aayog.

Table 1 indicates the values of protein, fat, and carbohydrate intake of the people residing in various Indian states. With the help of Table 1 and Eq. (15)–(17), one can calculate the entropy production on the bases of protein, fat, and carbohydrate.

Entropy production due to protein intake in Andhra Pradesh:

$$\frac{59.3}{1000} \times 66.77 \frac{kJ}{K\ kg} = 3.95 \frac{kJ}{K\ kg\ food} \quad (18)$$

Entropy production due to fat intake in Andhra Pradesh:

$$\frac{55.2}{1000} \times 86.36 \frac{kJ}{K\ kg} = 4.76 \frac{kJ}{K\ kg\ food} \quad (19)$$

Entropy production due to carbohydrate intake in Andhra Pradesh:

$$\frac{356.7}{1000} \times 36.52 \frac{kJ}{K\ kg} = 13.02 \frac{kJ}{K\ kg\ food} \quad (20)$$

Total Entropy Production due to protein, fat, and carbohydrate 3.95 + 4.76 + 13.02 = 21.73 $\frac{kJ}{K\ kg\ food}$

Entropy production rate can be calculated by multiplying the food consumption rate in kg/sec per capita: (As per the NIN, Hyderabad, the average cooked food intake by the Indian Nationals is 1.25 kg/day per person).

$$21.73 \frac{kJ}{K\ kg\ food} \times \left(1.44 \times 10^{-5}\right) \frac{kg}{sec} = 31.29 \times 10^{-5} \frac{kW}{K} \quad (21)$$

Entropy Production rate per unit mass: (As per the world bank report the average mass of a human is 62 kg)

$$\frac{31.29 \times 10^{-5}}{62} \frac{kW}{K\ kg} = 0.504 \times 10^{-5} \frac{kW}{K\ kg} \quad (22)$$

Silva and Annamalai have estimated the value of entropy production in the whole life of human in per kg of human and that value is 11404 kJ/kg K. With the assistance of this entropy production, one can determine the life cycle of the human body residing in any part of the world. Here life cycle has been calculated for Indian people living in different states of the nation.

Life cycle calculation for People of Andhra Pradesh:

$\frac{11404}{0.504 \times 10^{-5}} \times \frac{1}{365 \times 24 \times 3600} = 71.74$ Years

In this work, the life cycle is calculated only on the bases of metabolic reaction due to food intake. No other factors have been considered in this work. If other factors like water and air intake, is considered, then life span will be decreasing as per WHO norms. Similarly, entropy production per unit mass and life span has been calculated for the other Indian States and shown in Table 3(d).

5.1. Discussion

Fundamentally the second law of thermodynamics shows that, if the entropy production in any system is less than the system has more efficient and needs less maintenance. If the entropy of the system is zero, then this will be the ideal state. In this work, entropy production per unit mass has been calculated on the bases of protein, fat and carbohydrate intake, and subsequently, life span has been calculated. From the Table 3(d), one can find that Tamilnadu has minimum entropy production 19.71 kJ/K-kg-food among all the states, and Haryana has the highest entropy generation of 23.59 kJ/K-kg-food. All the states have the total entropy production due to protein, fat, and carbohydrate in the range of 19.71–23.59 kJ/K-kg-food and average entropy generated for all the states is
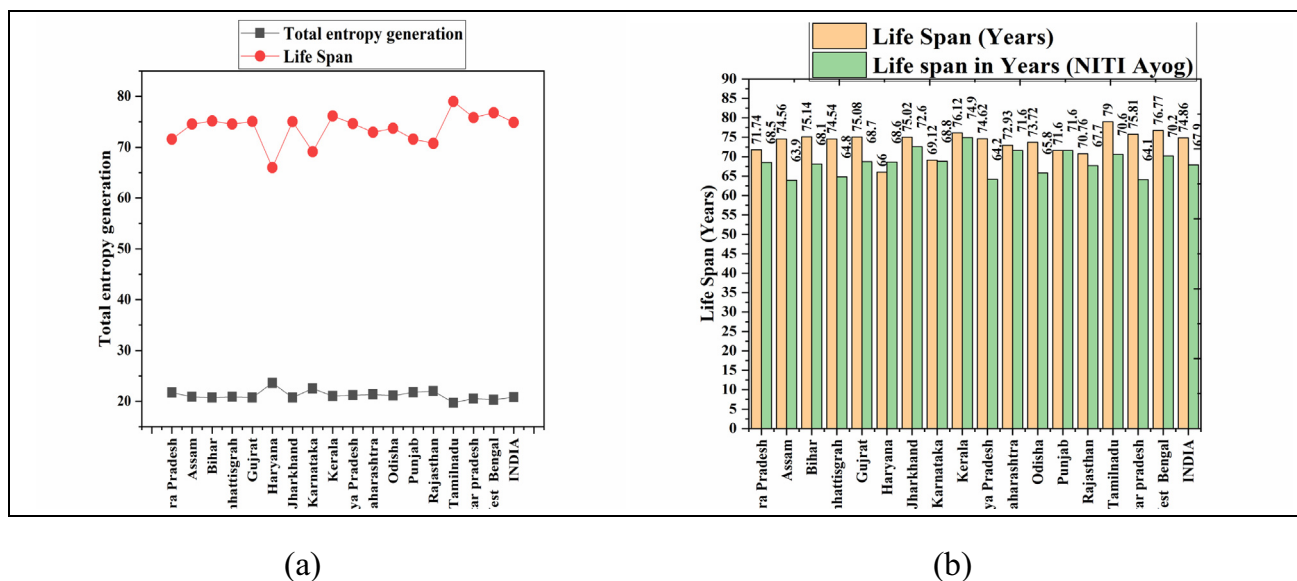

Fig. 2. (a) Entropy generation and Thermodynamic Life span analysis for all Indian states. (b) Comparison of thermodynamic life span estimation of humans for all Indian States with NITI Aayog life expectancy.

20.83 kJ/K-kg-food (INDIA). Total entropy generation due to protein, fat and carbohydrate in the states like Assam, Bihar, Chhattisgarh, Gujarat, Utter Pradesh and West Bengal are varying in the range of 20.30–20.89 kJ/K-kg-food. In states Andhra Pradesh, Kerala, Madhya Pradesh, Maharashtra, Odisha and Punjab it lies in the range of 21.05–21.71–4 kJ/K-kg-food. From Fig. 2(a), it is clear that if the entropy production rate increase, the duration of the life cycle will decrease. The entropy production rate in all states varies in the range of 28.38×10^{-5}–33.97×10^{-5} kW/K. Entropy production rate in the human body mainly depends upon core temperature and metabolism efficiency. Rate of entropy production is recorded highest in Haryana is 33.97×10^{-5} kW/K, and lowest in

Tamilnadu 28.38×10^{-5} kW/K and entropy production in all other states varies in between Haryana and Tamilnadu. The entropy production rate in states like Chhattisgarh, Kerala, Madhya Pradesh and Maharashtra lies in the range of 30.05×10^{-5}–30.74×10^{-5} kW/K. Utter Pradesh and West Bengal show close variation in case of Entropy production rate. Similarly, Gujrat and Jharkhand also have entropy production rate very similar to each other.

Another parameter to examine the life cycle of humans is entropy production rate per unit mass which is shown in Table 3 If the entropy production rate per unit mass is more, then overall entropy production will increase, which reduce the life span. Hence a light exercise is always recommended to reduce the total
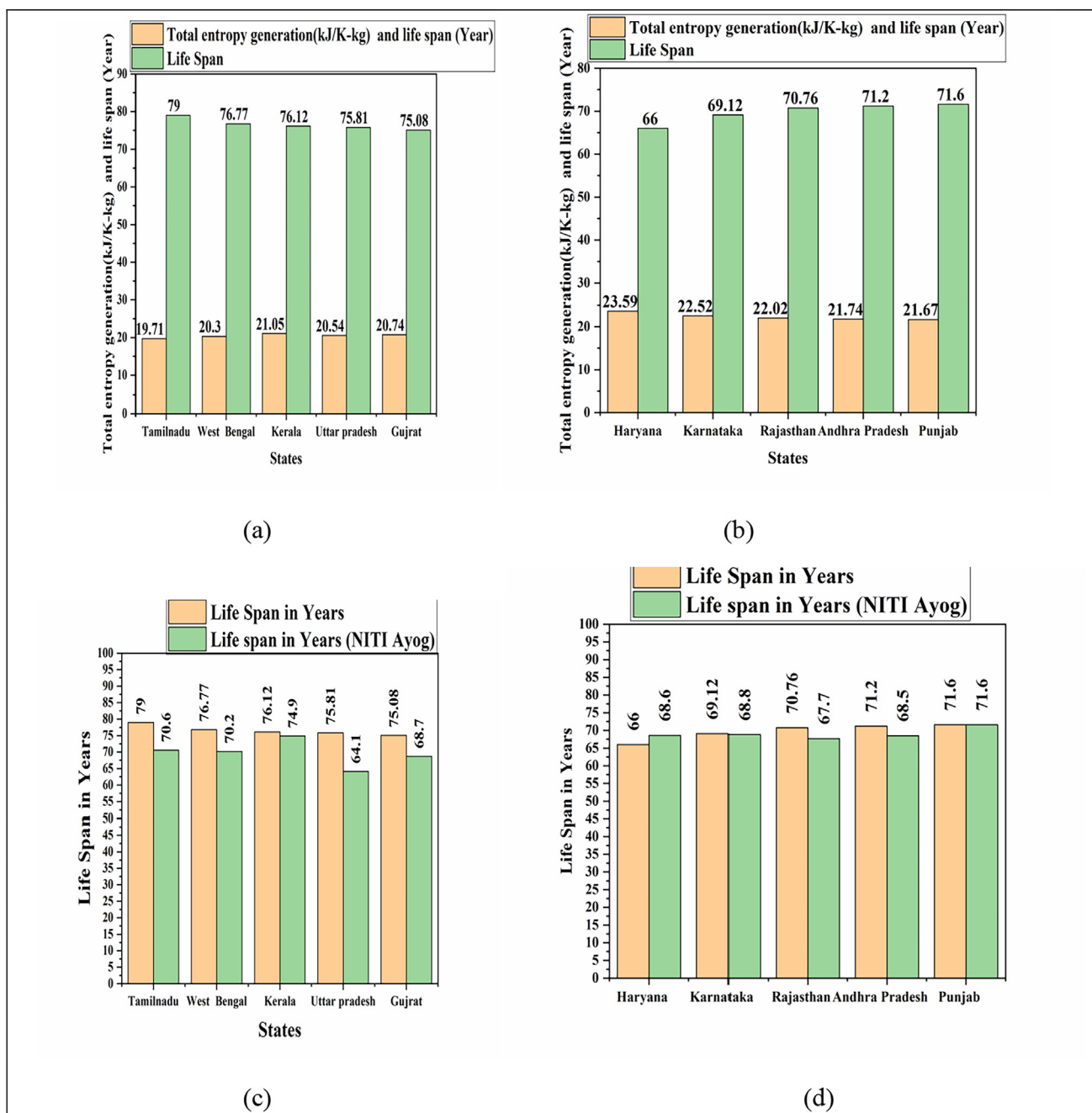

Fig. 3. (a) Comparison of Entropy production and life span estimation for the top five states. (b) Comparision of Entropy production and life span estimation for the least five states. (c) Comparison of the thermodynamic life span of human with NITI aayog life expectancy for top five states. (d) Comparision of the thermodynamic life span of human with NITI aayog life expectancy for least five states.

entropy production from the human body. In present work, entropy production per unit mass is maximum in case of Haryana, and it is minimum in Tamilnadu. States like Karnataka and Rajasthan also has high entropy production rate per unit mass. From the present study, one can conclude that food which has high palmitic acid contribute more to entropy production than carbohydrate and amino acids. Hence in general diet, it is recommended that one should consume more protein and amino acids.

Another important finding of this research work is to determine the life span of urban people living in different Indian states on the parameter of total entropy production in whole life. Fig. 3 (a&b) shows persons residing in Tamilnadu has the highest life span, and Haryana has the least life span. Tamilnadu people have an average life span of 79 years, and Haryana has just 66 years. Fig. 3(a) and (b) also show the effect of total entropy generation on the thermodynamic life span of humans. This life span for Tamilnadu, Haryana, and all other Indian states is determined on the bases of total intake of protein, fat, and carbohydrate (in gms) per person per day. The main reason for the highest life span of Tamilnadu and Kerala is more consumption of carbohydrate and less fat compared to Haryana. In Haryana consumption of the dairy product is more which the primary source of fat accumulation is. In Andhra Pradesh, Karnataka, Punjab and Rajasthan show the thermodynamic life span in the range of 69–72 years. States like Bihar, Gujarat, Jharkhand, Kerala, Utter Pradesh and West Bengal recorded the life span more than 75 years. States like Madhya Pradesh, Maharashtra and Odisha show the life span more than 72 years but bellow 75 years. One of the main reasons for the variation of life span is different climatic condition and changed food habits to obtain protein, fat and carbohydrate.

5.2. Comparison of result with the NITI aayog report

To validate the current research work, the life span of humans in different Indian states compare with a life expectancy of NITI Aayog data (Healthy states progressive India, 2019). Fig. 3(c), (d) & Table 3(d) shows the variation in the thermodynamic life span of humans with NITI Aayog life expectancy for all states. Although the parameters used by NITI Aayog is different, this comparison gives a brief insight into the authenticity of this research work. Life expectancy determined by NITI Aayog is less as compare to this work because, in the present work, only food habits of peoples is considered in stable conditions. If the author examines the impact of physical exercise, then life expectancy will go down, which is natural. Fig. 3(c&d) shows the comparison of thermodynamic life span for top-five and least five states with a life expectancy of NITI Aayog. According to NITI Aayog data, Kerala has the highest life span, but the difference in the life span of Kerala is just 1.2 years when compared with current work, this shows good accuracy. In case Punjab, the life span determined by the author is the same as the identified by the NITI Aayog. The life span of Utter Pradesh shows the highest deviation by 11.7 years when compared with the NITI Aayog calculation. Tamilnadu has life expectancy eight years more as compare to NITI Aayog.

6. Conclusion and recommendations

Entropy production in human is a unique problem and not address yet, especially in the context of India. The life span of humans is determined in this work and compared with the established data and NITI Aayog report on life expectancy. On the bases of the above research work, the following conclusion may be drawn.

1. The total entropy production due to protein, fat, and carbohydrate is highest in Haryana and lowest in Tamilnadu.
2. Entropy production in kW/K is very much similar in case of Rajasthan, Punjab and Andhra Pradesh. The entropy production rate is highest in Haryana and lowest in Tamilnadu.
3. Life span estimation of Tamilnadu is highest among all Indian states, and lowest life expectancy is recorded in Haryana.
4. Life expectancy data of NITI Aayog is compared with current research work, and there is a minor difference of 1.22 years in case of Kerala when compared. The highest difference is recorded in Utter Pradesh.

There is a strong need to investigate the impact of water intake and air intake on the effects of entropy production and human life span. One can also include the data for rural India and calculate the entropy production and compare with the urban area result.

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