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Impact of Beetroot Juice Supplementation on Physiological Variables of Individuals Exposed to High Altitude

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Abstract

Background and Objective: High altitude (HA) environment is challenging for lowlanders ascending to mountains for diverse reasons and poses multiple physiological and metabolic changes to acclimatize. There are several different strategies that can be employed for effective HA acclimatization such as gradual ascent, nutritional approach, medicines, or supplemental oxygen. Beetroot is a rich source of dietary nitrate, antioxidants, minerals and emerged as a potential ergogenic aid to improve oxygen delivery and vascular function. This study aimed to investigate the effect of beetroot juice (BRJ) supplementation on individuals exposed to the HA environment. **Methods:** In this study total of 92 individuals were accessed, which were grouped as Control (n=40) and BRJ supplemented (n=52). Anthropometric and physiological measurements were recorded, and blood samples were collected at sea level (SL, 122m) and HA (3300m). Key measures included systolic and diastolic blood pressure (SBP and DBP), heart rate (HR), and peripheral oxygen saturation (SpO_2), hemoglobin (Hb). **Results:** BRJ supplementation significantly ($p > 0.05$) improved SBP, DBP, HR, and SpO_2 at HA as compared to the Control group. Additionally, BRJ was associated with an increase in Hb ($p<0.5$) levels, indicating enhanced oxygen-carrying capacity. **Conclusion:** BRJ supplementation demonstrated a positive impact on key physiological variables, such as blood pressure regulation, heart rate stabilization, and oxygen saturation at HA. The observed improvements in Hb levels suggest that BRJ may facilitate better oxygen utilization and improved acclimatization at HA, positioning it as a promising nutritional intervention for individuals exposed to hypobaric hypoxia.

Keywords: Beetroot; High altitude; Hypoxia; Acute mountain sickness; Blood pressure

1 Introduction

High altitude refers to the elevation above 2000m from sea level. The increasing altitude results in decreased barometric pressure and so the decrease in partial pressure of oxygen. People exposed to the HA environment encounter a number of challenges like hypoxia, cold and dry weather, solar radiation, and high velocity wind. This extreme environment at HA may lead to dehydration, anorexia, and lack of nutrition which impact their health and physiological performance adversely[1]. Hypoxia is the most prevalent challenge endured at HA. Yet, it became very common for people to visit HA either for adventure, sports training, or recreational purposes. HA hypoxic environment causes decreased oxygen saturation in arterial blood which triggers several physiological and molecular responses in humans like hyperventilation, increased HR, cardiac output, and erythropoiesis to acclimatize this extreme condition. In spite of these adaptive responses, people ascending to HA are always at risk of developing altitude sickness like acute mountain sickness (AMS), high altitude cerebral edema (HACE), and high altitude pulmonary edema (HAPE) which can be fatal if not cured on time[2]. Therefore, it is very essential to apply a holistic approach to mitigate the uncertainty of altitude sickness and to improve the physical performance that includes gradual induction along with dietary and therapeutic intervention. Individuals who are prone to mountain sickness, ascending rapidly, or suffering from mountain sickness are administered either supplemental O_2 or medications like acetazolamide, dexamethasone, or nifedipine to alleviate HA symptoms[3]. All these treatments have certain limitations and disadvantages (side effects), so researchers are exploring some natural substances to mitigate the adverse effects of HA exposure.

In recent years, beetroot supplementation has emerged as a superfood due to its nutritional and medicinal properties. Beetroot (Beta vulgaris) is a rich source of proteins, carbohydrates, fibers, phytochemicals, and bioactive compounds. It contains nitrates, vitamins, minerals, flavonoids, phenolic compounds, betalains, and carotenoids. It has vasodilatory, anti-microbial, anti-inflammatory, and antioxidant properties[4]. Research shows that consumption of beetroot is helpful in the treatment of various diseases due to its wide range of properties and components. In the last few years, nitrate has also received considerable attention as a precursor of nitric oxide (NO), formed via nitrite conversion. NO is a potent signaling molecule that helps in vasodilation, lowering of blood pressure, and increasing oxygen delivery[5], which are the pre-requisite parameters required for the acclimatization during HA expedition. Beetroot is a natural source of nitrate along with components carrying anti-microbial, anti-inflammatory, and antioxidant properties. This makes beetroot a suitable candidate to be used as a dietary intervention to beat the HA consequences. There are several studies which have been previously reported that beetroot supplementation helps in lowering blood pressure[6,7], improve SpO_2 and time trial performance[6–11]. However, there are also studies suggesting no effect of beetroot supplementation[12–14]. Therefore, in the present study, we aimed to explore the effect of BRJ supplementation on physiological changes, physical performance and hematological indices at HA in order to improve the health of individuals expediting for training at high altitude.

2 Material and Methods

2.1 Study design and participants

This was a randomized controlled trial of trained healthy Indian males taking part in the BRJ intervention study. The study protocol was approved by the ethical committee of the institute (Defence Institute of Physiology and Allied Sciences, Delhi). All the participants were informed about the study and read and signed the informed consent forms. They were instructed to refrain from consuming alcohol and smoking throughout the trail. A total of 126 individuals were recruited, Control (n=63), BRJ supplemented (n=63). All the participants included in this study were healthy, similar food (dining from the same mess and ad-libitum) and engaged in routine physical activity, none of the participants from both the groups had a previous exposure to high altitude. Exclusion criteria involve: Individuals with history, sign, symptoms or medication of any chronic disorders like diabetes, cardiovascular disease or neurological disorder.

2.2 Study Setting

SL measurements were taken at an altitude of 122m. After SL measurements, all the participants were randomized into two groups (Group I-Control and Group II-BRJ supplemented) and each group comprised 63 individuals. All the participants were inducted to HA (Western Himalayas-3300m) via road (it took about 12hrs to attain the desired altitude). Thirty-four participants have been dropped out of the study due to unavoidable circumstances (logistic problems) and a total of 92 participants have taken part in the study (Figure 1).

2.3 Beetroot Intervention

Beetroot supplementation was provided in the form of beetroot powder packed in individual sachets (spray dried-40gms), reconstituted in 200ml of water before consumption for 15 days. The Control group remained devoid of any supplementation during this period. All participants from the test group consumed this juice every day in the morning after breakfast. All the measurements were repeated on the 3rd day (HA0) of arrival at HA before starting supplementation and on the 8th (HA1) and 16th day (HA2) of supplementation.

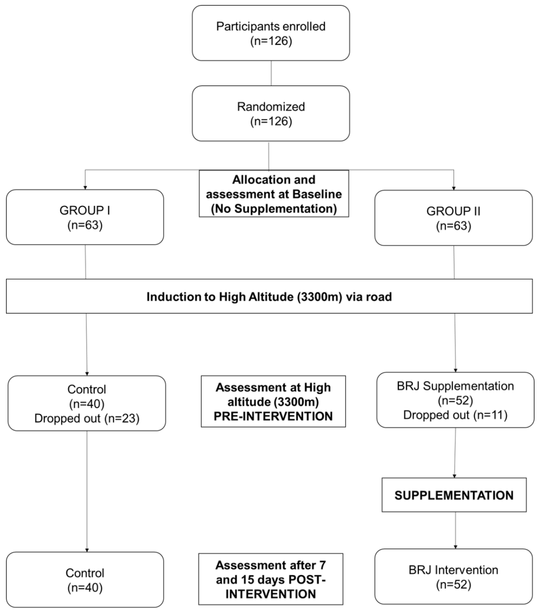

Fig 1. CONSORT Flow Chart of participants recruited, inducted to high altitude, numbers followed up and included for the analysis

2.4 Acute Mountain Sickness (AMS) Symptoms

All the participants of the study completed the self-reporting Lake Louise AMS questionnaire every day in the morning for seven consecutive days after reaching HA. They scored their symptoms (headache, gastrointestinal symptoms, fatigue, and dizziness) on a scale of zero to three (0-no symptom, 1-mild, 2-moderate, and 3-severe). The overall AMS score is the sum of all the values from each category. An individual will be diagnosed with AMS if had a Lake Louise Score (LLS) of ≥ 3[15].

2.5 Basic Physiological measurements and sample collection

All the measurements and sample collection were done in the morning (6-8 am) including height and weight. Each participant rested for 10-15 min in a supine position before the measurement of SBP and DBP using a mercurial BP apparatus (Diamond Deluxe, India) along with HR and SpO_2 using finger pulse oximeter (Nonin Medical Inc. USA). Whole blood was collected from the antecubital vein after fasting of 12 hours in EDTA vacutainers and used to measure hematological parameters (H 360, Erba, Slovakia), within 30 minutes of collection.

2.6 Body Composition

Body composition was measured using Bioscan 920-II, a multi-frequency analyzer (Maltron, UK). All participants were restricted from wearing any metal on their bodies during the test. Each of them was instructed to be in a supine position with arms and legs apart. The electrodes were firmly attached to the carpal, meta-carpal, talus, and, metatarsal. The test was performed using the right side of the subject. The test was performed at each time interval except HA2 due to some logistic issues.

2.7 Physical Performance

Queen's College Step Test[16] is a submaximal exercise test, used to evaluate the maximum oxygen consumption (VO_2 max). The test was performed by all the participants at SL, HA1, and HA2 on a stool of 16.25 inches. After completion of the test, carotid pulse was measured in a standing position for 15 seconds. The following equation has been used for the calculation of the maximum oxygen uptake capacity:

VO_2 max (ml/kg/min) = 55.23 – (0.09 x pulse rate in beats/min)

2.8 Statistical analysis

Demographic data has been represented as mean $\pm$ SD. Physiological and biochemical data have been represented as mean $\pm$ SEM. The data analysis was executed using GraphPad Prism software, version 8 (GraphPad, USA). The D'Agostino-Pearson omnibus normality test was used to check the normal distribution of data. A Repeat Measure two-way ANOVA was used to compare the time points of each group from SL with the Bonferroni post hoc test. An unpaired t-test was used to measure the effect of supplementation between the groups at different time intervals. For the statistical significance, a p-value of < 0.05 is considered.

3 Results

3.1 Sea Level Measurements

All participants in the Control and supplemented group were similar in age, weight, and height. Table 1 represents the basic characteristics of all the participants. We observe no significant difference in the SBP, DBP, HR, and SpO_2 between the two groups at SL (Table 2). Body composition parameters and VO_2 max values were also similar in both the groups at SL (Table 4 and Figure 2).

Table 1. Participant's details

Parameters	Control (n=40)	BRJ supplemented (n=52)
Age, (mean $\pm$ SD) years	27 $\pm$ 5.7	28 $\pm$ 6.6
Height, (mean $\pm$ SD) cm	172.2 $\pm$ 4.6	171.5 $\pm$ 4.5
Body weight, (mean $\pm$ SD) kg	67.8 $\pm$ 7.0	67.4$\pm$ 7.3

Table 2. Comparative changes in physiological parameters in control and BRJ supplemented group at sea level and high altitude

Parameters	Group	SL	HA0	HA1	HA2
Systolic blood pressure (mmHg)	Control	114.9 ± 1.3	122.2 ± 1.3***	121.4 ± 1.3***	119.3 ±1.3***
	BRJ supplemented	115.0 ± 1.1	121.7 ± 1.1***	117.7 ± 1.0*** #	115.7 ± 1.0 #
Diastolic blood pressure (mmHg)	Control	75.3 ± 0.95	78.8 ± 0.91***	79.5 ± 1.0***	77.9 ± 0.91***
	BRJ supplemented	74.5 ±0.77	78.6 ± 0.77***	76.9 ± 0.80***#	75.9 ±0.88**
Peripheral oxygen saturation (%)	Control	97.55 ± 0.13	91.80 ± 0.25***	92.75 ± 0.25 ***	93.18 ± 0.30***
	BRJ supplemented	97.44 ± 0.12	91.98 ±0.26***	93.08 ± 0.23***	94.00 ± 0.20***#
Heart rate (bpm)	Control	67.58 ± 1.2	77.78 ± 1.4***	75.05 ± 1.2***	72.28 ± 1.3***
	BRJ supplemented	67.92 ± 1.0	77.79 ± 1.1***	71.38 ± 1.2***#	68.73 ±1.1 #

Values are represented as mean ± SEM. Statistical significance in Control and BR group in comparison to SL measurements is represented as *p < 0.05, **p < 0.01, ***p <0.001 for each time interval. Statistical significance between control and BRJ supplemented group at different time interval is represented as #p < 0.05, ##p < 0.01, ###p < 0.001.

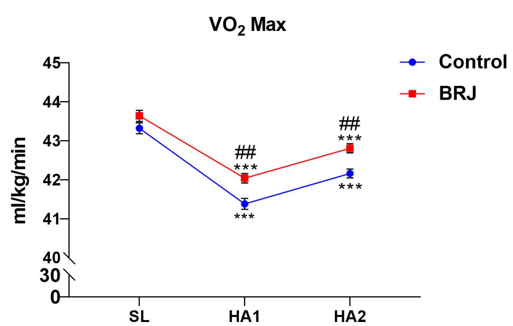

Fig 2. Representation of maximum oxygen consumption (VO_2 max) values at SL, HA1 and HA2. Values are represented as mean ± SEM. Statistical significance in control and BRJ supplemented group in comparison to SL measurements is represented as *p < 0.05, **p < 0.01, ***p < 0.001 for each time interval. $^{\#}p < 0.05$, $^{\#\#}p < 0.01$, $^{\#\#\#}p < 0.001$ represents the significance between Control and BRJ supplemented group at that particular time interval

3.2 Physiological measurements

Physiological measurements including SBP, DBP, HR, and SpO_2 are summarized in Table 2. Induction to HA affects all the resting parameters. SBP and DBP increased significantly ($p < 0.001$) in response to HA exposure (HA0) in both the groups as compared to their SL values, thereafter it started decreasing but non-significantly in the Control group. The decrease in SBP and DBP was significant ($p < 0.05$) in the BRJ supplemented group on HA1 and HA2 as compared to the Control group. A similar response has been observed for resting heart rate in both groups. SpO_2 decrease ($p < 0.001$) was recorded upon induction to HA in both the groups as compared to SL, which starts improving thereafter. The BRJ supplemented group showed significant amelioration in SpO_2 levels on HA2 in comparison to the Control group.

3.3 Hematological observations

A slight increase in mean Hb, red blood cells (RBC), and total hematocrit (Hct) was seen in both groups on HA exposure (Table 3). The increase was significant ($p < 0.001$) in both groups at each time point in comparison to SL. However, the increase in Hb was slightly greater ($p < 0.05$) in the BRJ supplemented group on HA1 and HA2 as compared to the Control counterpart. No difference was observed for RBC count and total Hct between both groups at any time point.

3.4 Body Composition

The body composition was measured by a Bio-electrical impedance analyzer. The results are represented in Table 4. There was a significant decrease in weight and basal metabolic index (BMI) in both groups upon induction to HA. A significant decrease was observed in total body water (TBW) on induction to HA in the Control group while the BRJ supplemented group showed no significant decrease in TBW. The percentage of extra-cellular water (ECW) was found slightly increased after induction to HA in both the groups. Intra-cellular water (ICW) was significantly decreased in the Control group on HA0 and HA1 while the decrease was significant on HA1 in the BRJ group. Although, we observed changes in body composition parameters in both groups as compared to their SL values, but no significant changes were found between both the groups at any time point, which suggests that the changes were due to ascent to HA.

3.5 Physical performance

The results of Queen's College Step Test for the VO_2 max were represented in Figure 2. HA induction results in a great decrease ($p < 0.001$) in VO_2 max values in both the group on HA1 and HA2. However, the decrease in VO_2 max values exhibited in the BRJ group is less as compared to the Control group at each time point at HA.

Table 3. Comparative changes in RBC count, Hb and Hct in Control and BRJ supplemented group at SL, HA0, HA1 and HA2

Parameters	Group	SL	HA0	HA1	HA2
RBC ($10^6/\mu$l)	Control	4.65± 0.07	5.07 ± 0.07 ***	5.25± 0.07 ***	5.33± 0.07 ***
	BRJ supplemented	4.79 ± 0.06	5.10 ± 0.05 ***	5.37 ± 0.05 ***	5.43 ± 0.05 ***
Haematocrit (%)	Control	44.06 ± 0.49	45.18± 0.48***	46.32± 0.50***	46.56 ± 0.48***
	BRJ supplemented	44.23± 0.40	45.53± 0.40***	46.73 ± 0.38***	47.03± 0.35***
Haemoglobin (g/dL)	Control	13.66± 0.14	14.50± 0.16 ***	15.04± 0.16 ***	15.46± 0.17 ***
	BRJ supplemented	13.60 ±0.11***	14.48 ± 0.13 ***	15.64± 0.13 ***##	15.92±0.13 ***#

Values are represented as mean ± SEM. Statistical significance in Control and BRJ supplemented group in comparison to SL measurements is represented as *p < 0.05, **p < 0.01, ***p < 0.001 for each time interval. #p <0.05, ##p < 0.01, ###p < 0.001 represents the significance between Control and BRJ supplemented group at that particular time interval.

Table 4. Comparative changes in body composition variables in Control and BRJ supplemented at SL, HA0, HA1 and HA2

Parameters	Group	SL	HA0	HA1	HA2
Weight (kg)	Control	67.89 ± 1.13	67.41 ± 1.14 *	66.51 ± 1.14 ***	66.27 ± 1.12 ***
	BRJ supplemented	67.40 ± 1.01	66.36 ± 1.00 ***	65.30 ± 1.00 ***	65.47 ± 0.96 ***
Basal Metabolic Index	Control	22.99 ± 0.43	22.90 ± 0.44	22.62 ± 0.43	22.37 ± 0.43 ***
	BRJ supplemented	22.78 ± 0.35	22.59 ± 0.38	22.16 ±0.35 ***	22.07 ± 0.33 ***
Total Body Water (%)	Control	61.77 ± 0.99	60.55 ± 0.91**	60.28 ± 0.85 ***	
	BRJ supplemented	61.18 ± 0.72	60.50 ± 0.70	60.72 ± 0.65	
Extra Cellular Water (%)	Control	41.37 ± 0.30	42.02 ± 0.095*	41.91 ± 0.10*	
	BRJ supplemented	41.51 ± 0.24	41.92 ± 0.12	42.03 ± 0.12*	
Intra Cellular Water (%)	Control	58.65 ± 0.29	57.97 ± 0.095**	58.08 ± 0.10*	
	BRJ supplemented	58.45 ±0.24	58.07 ± 0.12	57.96 ± 0.12*	

Values are represented as mean ± SEM. Statistical significance in Control and BRJ supplemented group in comparison to SL measurements is represented as *p < 0.05, **p < 0.01, ***p < 0.001 for each time interval.

3.6 AMS Symptoms

Table 5 **(a)** and **(b)** represent the total AMS LLS and score for each symptom of AMS for both groups. Altitude effects on AMS LLS were apparent in both the groups on initial three days but it normalized afterwards. There was no significant difference observed between both the groups. We observed no case of AMS in either group during the study.

4 Discussion

Beetroot supplementation has become popular in the last few years due to its various medicinal properties. The present study aimed to investigate the effect of BRJ supplementation on different physiological responses, hematological indices, and physical performance in healthy human males exposed to HA. The present study was a field trial and employs a repeated measure design, which enables the collection of measurements at different time intervals, which is particularly useful for longitudinal studies where change over time is assessed.

In our study, all the participants were subjected to 18 days of high-altitude hypoxia exposure. All the participants had an increase in blood pressure, HR, and hematological parameters in response to hypoxic stress. The purpose of the study was to determine whether BRJ supplementation has any favorable impact on conquering HA-associated problems and our findings imply that BRJ supplementation is beneficial at HA. However, it is important to note that although our results are different from studies[17–19] who reported no effect of BRJ supplementation on the blood pressure, SpO_2, and HR, they have similarities with some previous studies[6,11,20–22].

The primary findings of the study showed an improvement in SBP and DBP, HR, and SpO_2 in BRJ supplemented group at HA. Our findings are consistent with previous studies conducted on healthy individuals in plains, which found that consuming BRJ from one to several days can effectively lower BP[6,20–22]. Another study by Shannon at moderate and very high simulated altitude demonstrated the elevated SpO_2 in the beetroot supplemented group[10,11]. These similar results suggest the beneficial effect of beetroot on cardiovascular health at HA which is contributed by its vasodilatory action. We also observed a decrease in body weight and BMI on exposure to high altitude in both the groups. The reduction in partial pressure of O_2 at HA results in lower physical performance of an individual during the expedition, which has been observed during the study. Previous studies suggest that consumption of beetroot increases the VO_2 max[23–26]. Thus, we also investigated the metabolic response post BRJ supplementation during exercise at HA and we found that

Table 5. AMS symptoms

(a) Number (percentage) of participants reporting AMS Score on different days at high altitude in the Control group. HAD refers to High Altitude Day and the numbers denotes the day on which AMS score has been recorded

Parameters		HAD1 n (%)	HAD2 n (%)	HAD3 n (%)	HAD4 n (%)	HAD5 n (%)	HAD6 n (%)	HAD7 n (%)
Headache	None	29 (73)	32 (82)	35 (88)	34 (85)	36 (90)	39 (98)	37 (93)
	Mild	9 (23)	6 (15)	4 (10)	5 (13)	1 (3)	1 (3)	1(3)
	Moderate	2 (5)	2 (5)	1 (3)	0 (0)	3 (8)	0 (0)	2 (5)
	Severe	0 (0)	0 (0)	0 (0)	1 (3)	0 (0)	0 (0)	0 (0)
Gastro-intestinal symptoms	None	38 (95)	39 (98)	40 (100)	38 (95)	37 (92)	37 (92)	38 (94)
	Mild	2 (5)	1 (3)	0 (0)	2 (5)	3 (8)	3 (8)	1 (3)
	Moderate	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (3)
	Severe	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Fatigue/weakness	None	26 (65)	30 (75)	33 (83)	34 (85)	33 (83)	35 (88)	39 (98)
	Mild	12 (30)	7 (18)	6 (15)	6 (15)	7 (18)	5 (13)	1 (3)
	Moderate	2 (5)	1 (3)	1 (3)	0 (0)	0 (0)	0 (0)	0 (0)
	Severe	0 (0)	2 (5)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Dizziness/light-headedness	None	38 (95)	39 (98)	36 (90)	38 (95)	40 (100)	39 (98)	39 (98)
	Mild	2 (5)	1 (3)	4 (10)	2 (5)	0 (0)	1 (3)	1 (3)
	Moderate	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Severe	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Total AMS Score	None	35 (88)	36 (90)	38 (95)	39 (98)	40 (100)	39 (98)	40 (100)
	Mild	5 (13)	4 (10)	2 (5)	1 (3)	0 (0)	1 (2)	0 (0)
	Moderate	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Severe	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

(b) Number (percentage) of participants reporting AMS Score on different days at high altitude in the BRJ supplemented group. HAD refers to High Altitude Day and the numbers denotes the day on which AMS score has been recorded

Parameters		HAD1 n (%)	HAD2 n (%)	HAD3 n (%)	HAD4 n (%)	HAD5 n (%)	HAD6 n (%)	HAD7 n (%)
Headache	None	40 (77)	42 (81)	48 (92)	46 (88)	47 (90)	49 (94)	48 (92)
	Mild	10 (19)	7 (13)	4 (8)	5 (10)	4 (8)	2 (4)	4 (8)
	Moderate	2(4)	3 (6)	0 (0)	1 (2)	1 (2)	1 (2)	0 (0)
	Severe	0 (0)	0(0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Gastro-intestinal symptoms	None	51 (98)	51 (98)	47 (90)	48 (92)	49 (94)	50 (96)	49 (94)
	Mild	1 (2)	1 (2)	5 (10)	4 (8)	3 (6)	2 (4)	2 (4)
	Moderate	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (2)
	Severe	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	(0)
Fatigue/weakness	None	41 (79)	40 (77)	43 (83)	41 (79)	44 (85)	41 (79)	45 (87)
	Mild	9 (17)	11 (21)	9 (17)	10 (19)	6 (12)	10 (19)	5 (10)
	Moderate	1 (2)	1 (2)	0 (0)	1 (2)	2 (4)	1 (2)	1 (2)
	Severe	1 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (2)
Dizziness/light-headedness	None	50 (96)	51 (98)	52 (100)	50 (96)	51 (98)	48 (92)	50 (96)
	Mild	2 (4)	1 (2)	0 (0)	2 (4)	1 (2)	4 (8)	2 (4)
	Moderate	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Severe	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Total AMS Score	None	50 (96)	52 (100)	52 (100)	49 (94)	50 (96)	50 (96)	52 (100)
	Mild	2 (4)	0 (0)	0 (0)	3 (6)	2 (4)	2 (4)	0 (0)
	Moderate	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Severe	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

supplementation of 8-15 days significantly helps in less decrease in VO_2 max. We also found a slight increase in Hb in the supplemented group which could be due to the high content of iron and folate in beetroot[27]. There are several other studies that showed a positive impact of beetroot consumption on hematological indices[4].

The results of the present investigation showed differences as well as similarities with the previous research. The discrepancies in the results could be due to differences in study design, sample size, age, ethnicity of participants, formulation of beetroot juice, difference in altitude, or duration of supplementation. Further research is required to optimize the dose and duration of supplementation for specific group or population and normal or extreme environment.

5 Conclusion

In conclusion, our study suggested the positive impact of BRJ consumption on physiological response and hematological variables at HA hypoxic environment, as well as an improvement in VO_2 max. These findings will be very helpful for people seeking to improve their physical performance and health in extreme environment and also suffering from diseases like hypertension. However, more research is required before the implementation of beetroot consumption in these conditions.

5.1 Acknowledgment

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5.2 Authorship contribution statement

Karishma Dohare: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Sample collection, Data curation, Writing-original draft. **Divya Singh:** Data curation, Study planning, Sample collection. **Praveen Vats:** Conceptualization, Methodology, Data curation, Writing- review and editing, Supervision, and Project administration. **Fakir Chand:** Sample collection. **Subhasis Bose:** Sample collection. **Rohit Kumar:** Sample collection.

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