

Effects of Natural Honey on Lipid Profile and Body Weight in Normal Weight and Obese Adults: A Randomized Clinical Trial

Rehana Mushtaq,¹ Rubina Mushtaq^{1*} and Zahida Tasawar Khan²

¹Department of Zoology, University of Balochistan, Quetta, Pakistan

²Institute of Pure and Applied Biological Sciences, Bahauddin Zakriya University, Multan, Pakistan

Abstract.- The effects of natural honey on body weight and blood lipid profile in both sexes of normal weight and obese adults have been investigated. Body mass index (BMI), total cholesterol (TC), triglyceride (TG), high density lipoprotein cholesterol (HDL-c) and low density lipoprotein cholesterol (LDL-c) were used as parameters of comparison of normal and obese adults. A non significant reduction in BMI was observed in all ethnic groups in both genders of obese as well as normal weight subjects. Honey intake significantly reduced TC in obese subjects of both genders of Baloch and Punjabi and Hazara females, in contrast to reduction in both genders of Baloch and males of Pathan normal weight control subjects. Triglycerides were lowered in obese subjects of all the ethnic groups of both the sexes except females of Hazara; comparably reduction was noticed in normal weight control males of Baloch and females of Punjabi only. The significant increases in HDL-c in obese of both the genders of Baloch and Pathan and males of Hazars, were observed and in normal weight controls similar response was shown in males of Pathan and Punjabi only. Significant decreases in the level of low density lipoprotein (LDL-c) cholesterol in obese subjects of all ethnic groups except females of Hazara and Punjabi were found compared to none of the significantly affected batch in the normal weight control group. Honey demonstrated prominent reducing effect on TC, LDL-c & TG and HDL cholesterol enhancing ability in the obesity of most of the ethnic groups in both the genders. Comparably lowering of TC, TG and increasing of HDL-c with honey is also observed in normal weight subjects, however, imperceptibly in very few ethnic groups. Thus honey consumption had shown exceedingly improving effect on lipid profile in obesity compared to normal weight status.

Key words: Cholesterol, honey, HDL cholesterol, LDL cholesterol, obesity, triglycerides.

INTRODUCTION

Honey has been used for as long as there has been medicine. In modern medicine, honey has been used for the treatment of respiratory, urinary and gastrointestinal disease; skin ulcers, wounds, eczema, psoriasis, dandruff, diaper dermatitis, and radiation mucositis. Laboratory studies and clinical trials have demonstrated that honey possesses a broad spectrum antimicrobial activity (Al-Waili and Saloom, 1999; Al-Waili, 2004a) and caused increased antibody production against thymus dependent and thymus independent antigens (Al-Waili and Haq, 2004). Consumption of honey decreased the concentrations of prostaglandins in the plasma of normal individuals (Al-Waili and Boni, 2003), and increased antioxidant agents, serum iron, and blood hematological indices (Al-Waili, 2003a). Honey intake increased insulin

secretion and decreased blood glucose levels (Al-Waili, 1999, 2003b). Al Waili (2004b) found that natural honey improved lipid profile, lowered normal and elevated C-reactive protein, lowered homocysteine, and decreased triacylglycerol in patients with hypertriglyceridemia.

Honey is said to be the best remedy for weight loss. It is the naturally occurring sweetener that contains a mixture of both simple and complex sugars, as well as vitamins, minerals, acids and enzymes (Molan, 1996). The consumption of honey showed a favorable effect on diabetes patients, causing a significant decrease of plasma glucose (Peretti *et al.*, 1994; Al-Waili, 2004b). Honey was well tolerated by patients with diabetes of unspecified type (Al-Waili, 2003b) and by diabetes type-2 patients (Bejan *et al.*, 1978; Bornet *et al.*, 1985; Katsilambros *et al.*, 1988).

In diabetic patients, honey compared with dextrose caused a significantly lower rise of plasma glucose (Al-Waili, 2004c). Bahrami *et al.* (2009) observed beneficial effects on body weight and blood lipids in 8-week consumption of honey in diabetic patients. In another study daily intake of

*Corresponding author: rmushtaq29@yahoo.co.uk

0030-9923/2011/0001-0161 \$ 8.00/0

Copyright 2011 Zoological Society of Pakistan.

honey solution or a honey-comparable sugar solution over a period of 14 days influenced significantly cholesterol or triglyceride values in the total group; in women, however, the LDL cholesterol value increased in the sugar solution subgroup but not in the women taking honey (Münstedt *et al.*, 2009). Consumption of natural honey has been reported to reduce cardiovascular risk factors, particularly, in overweight or obese subjects (Yaghoobi *et al.*, 2009).

Obesity is the syndrome of the recent life style and is result of excessive caloric consumption. In the view of the characteristics of honey reviewed above it will be a useful approach to investigate the ability of honey to affect body weight and modulate lipid profile in obese compared to normal weight subjects of various ethnic groups in the study area.

PARTICIPANTS AND METHODS

Study design

The study was performed in four parallel ethnic groups [Pathan (P), Baloch (B), Hazara (H) and Punjabi (Pu)] in Quetta, Balochistan, Pakistan. The population of city of Quetta well represents all these ethnic groups. The study was designed as intervention controlled clinical pattern trial with participant volunteers were recruited from the local community, primarily through newspaper advertisements, and through pasting posters in all departments of University of Balochistan, Bolan Medical College, hospitals, telephonic messages, emails and by counseling in different communities and also in various medical camps.

Selection of the subjects was based on WHO (1998) criteria where BMI = 30-34.9 is considered as obese I (at a moderate risk of co-morbidities), BMI = 35-39.9 is obese II (at a severe risk of co-morbidities), and BMI \geq 40 is obese III (at a very severe risk of co-morbidities).

Participants and recruitment

In various ethnic groups 526 obese subjects on the WHO criteria were identified and contacted for the trial. Similarly 710 normal weight subjects were contacted for the participation. The gender

distribution of 286 and 240 subjects was for the males and the females respectively in the obese category and 397 males and 313 female subjects in the normal weight category. Those who showed interest and commitment were specifically marked in both batches of obese and normal weight subjects. There was no specific reluctance in the participants due to general belief that honey in taking is beneficial for the health. Volunteers ranging mainly 40 to 50 years of age were screened and those were excluded from the trial if they consumed honey frequently, had known honey allergies, smoked cigarettes and had history of hypertension or atherosclerotic or metabolic disease. The ethical considerations of consent and willingness of participation in the project were obtained. Meetings with the selected volunteers were held to explain the protocol of the study.

A total of 40 obese males and 40 female obese subjects with the distribution of 10 from each ethnic sub-population were contacted and provided the natural honey and advised for the protocol of its consumption. Alshifa Natural Honey 'The Beehive' of Food and Fine Pastries Manufacturing Co., Ltd, Jeddah, Saudi Arabia was chosen for the study. All the subjects chosen for honey taking were asked to take daily 40g honey dissolved in tap water with their normal eating habit for four weeks. Another 40 obese males and 40 females to be taken as controls did not consume honey during trial period. Exactly the same plan was worked out in the case of normal weight category. A weekly monitoring was done in the case of honey in takers and missing doses were found in some cases. Eventually in both obese and normal weight subjects 8 volunteers from each ethnic group in each gender were selected with the least omission of the honey doses. In the comparable groups of obese and normal weight subjects of both the genders 8 volunteers again of each ethnic group with no honey consumption were approached a couple of days prior to blood sampling for reminding of 12 hours fasting. At the end of 4 weeks the night following the last dose subjects fasted for 12 hour and in the morning blood samples were taken. Finally it had been possible to obtain the blood samples from at least 128 volunteers of each gender in each batch of obese and normal weight subjects.

Assessment and measurements

The general data for the identifications and for BMI were also collected. The blood samples were subjected for estimation of total cholesterol, triglycerides, HDL cholesterol and LDL cholesterol with commercial kits (Human Gesellschaft fur Biochemica und Diagnostica mbH, Germany) under the similar laboratory conditions for all the control and honey takers groups.

Statistical analysis

Statistical analysis was undertaken with statistical program of Sigma Stat 3.5. Student t test was used for comparison between normal and obese subject groups and $P < 0.05$ was considered as statistically significant.

RESULTS

The general observations and of lipid profile in obese and normal weight honey takers and non honey takers were made for the comparison to assess the honey effects.

Age status

The average age in the normal weight males and females volunteers, not consuming honey, was 42.5 ± 1.78 and 42.91 ± 2.15 years respectively. In the honey in takers of the normal weight, however, it was 46.25 ± 3.51 years in the males and 42.81 ± 3.37 years in the female subjects. In case of not consuming honey control obese male and female subjects' average age was 39.87 ± 2.12 and 39.66 ± 2.53 years respectively. A mean age in the obese volunteers taking honey the values were 41.72 ± 2.85 and 40.06 ± 2.63 years in the males and the females respectively.

BMI

There were non significant reductions in BMI after taking 40 g honey daily for 4 weeks in all ethnic groups either from normal weight subjects and obese subjects of both the genders (Table I).

Cholesterol (Fig. 1)

There had been a general trend of decrease of total serum cholesterol following honey consumption in all ethnic groups, however, in males

of Baloch ($P < 0.001$) and Pathan ($P < 0.001$) group it was statistically significant, while Baloch females only showed significant ($P < 0.011$) reduction compared to their respective controls..

In obese, higher level of cholesterol was found in males compared to the females. The obese males and females of Baloch ($P < 0.011$, $P < 0.003$ respectively) and Punjabi ($P < 0.008$ and $P < 0.002$ respectively) ethnic groups showed statistically significant reduction in cholesterol of subjects taking honey compare to the respective non honey obese controls. Additionally obese females of Hazara ($P < 0.025$) also showed similar significantly lowering effect.

Significant lower fraction values were quite in contrast in obese and normal weight genders of different ethnic groups. In normal weight control category, Baloch of both gender and male Pathan only demonstrated significant results, whereas in obese subjects Baloch and Punjabis of both sexes and female Hazara exhibited significant decreases. In obese greater number of the groups exhibited significant lower values to their respective controls than in the normal weight subjects' category demonstrating greater cholesterol reducing effect of honey in obesity. In Baloch in both genders honey reduced cholesterol significantly in obesity as well as in normal weight status is noticeable.

Triglycerides (Fig. 2)

In this weight category merely Baloch male ($P < 0.001$) and Punjabi females ($P < 0.027$) subjects exhibited significant reduction in serum triglycerides compare to their respective controls.

The obese males of all the ethnic groups demonstrated marked and significant reduction {Baloch ($P < 0.002$), Pathan ($P < 0.001$), Hazara ($P < 0.004$) and Punjabi ($P < 0.001$)} in TG after taking honey. However, in case of females, the honey consumption in Baloch, Pathan and Punjabi groups caused noticeable and significant ($P < 0.001$), ($P < 0.025$), and ($P < 0.002$) reduction, respectively. Thus except females of Hazara in all others honey in obesity caused significant lowering of TG.

The comparison of the effects in the normal weight and the obese subjects evidently displayed TG lowering effect of honey in obese subjects regardless of ethnicity or the lifestyle and

Table I.- Body mass index Kg/m² of both the genders in the subjects of various ethnicities.

Ethnicity	Normal weight				Obese			
	No honey controls		Honey in takers		No honey controls		Honey in takers	
	Males	Females	Males	Females	Males	Females	Males	Females
Baloch	22.0±0.8	21.0±0.4	21.7±0.6	21.3±0.4	40.9±1.4	38.1±1.0	38.5±0.7	36.0±0.6
Pathan	22.1±0.5	21.0±0.6	23.0±0.4	21.1±0.3	40.6±1.3	40.4±0.8	38.5±0.8	38.6±0.6
Hazara	21.1±1.8	22.3±0.7	22.6±0.6	20.8±1.0	40.9±1.3	41.3±1.0	38.8±0.5	39.8±1.0
Punjabi	22.4±0.6	22.0±0.5	22.0±0.6	22.1±0.6	41.3±1.2	40.4±0.8	39.1±0.5	38.4±0.8

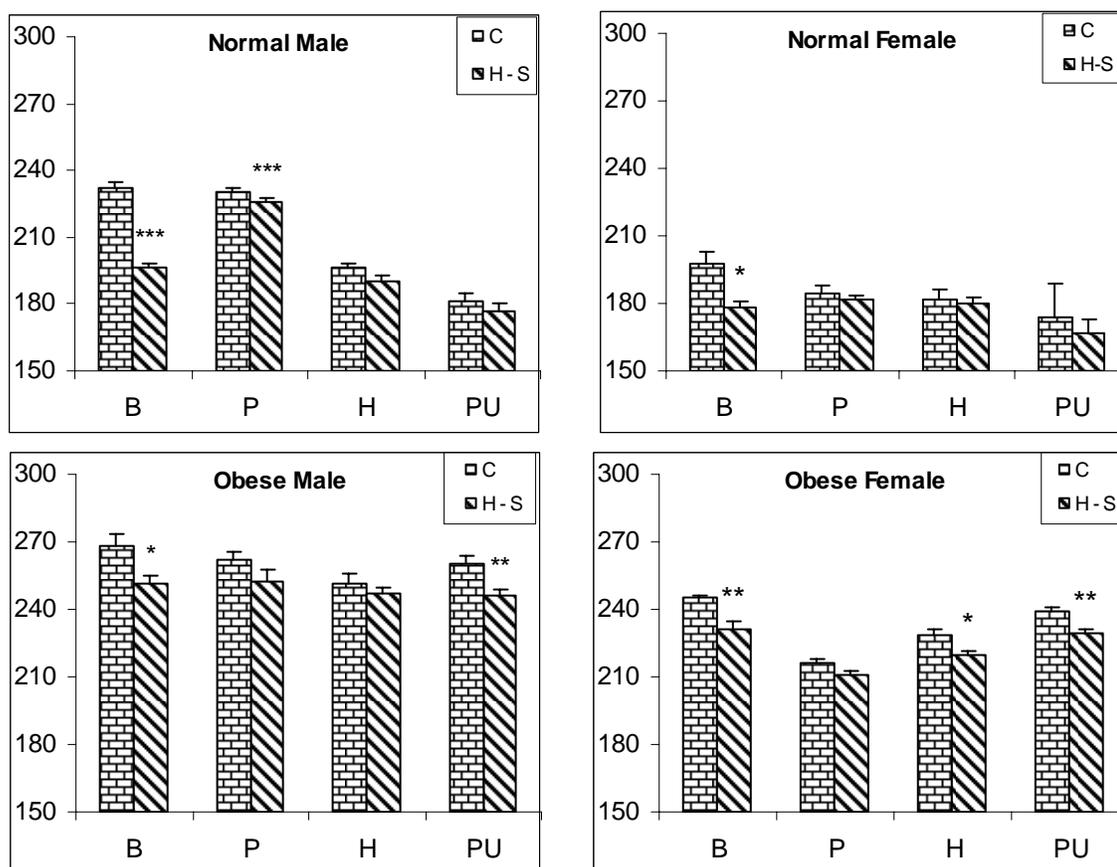


Fig. 1. Serum cholesterol (mg/dl) in the control (C) and obese males and females, before and after honey supplementation (H – S) in P (Pathan), B (Baloch), H (Hazara) and PU (Punjabi) ethnic groups. * P < 0.05, ** P < 0.01, *** P < 0.001.

the genetic background. It provides sufficient evidence to state that honey possesses TG lowering characteristics specifically in obese subjects.

HDL cholesterol (Fig. 3)

The results showed that honey caused significant increase (P < 0.018) and (P < 0.002) in

HDL level in normal weight males of Pathan and Punjabi respectively. Almost in all the ethnic groups in females increase was non significant statistically.

Honey consumption in obese males exhibited marked elevation in HDL level (P < 0.035), (P < 0.015) and (P < 0.005) in Baloch, Pathan and Hazara groups respectively. In case of females, only Baloch

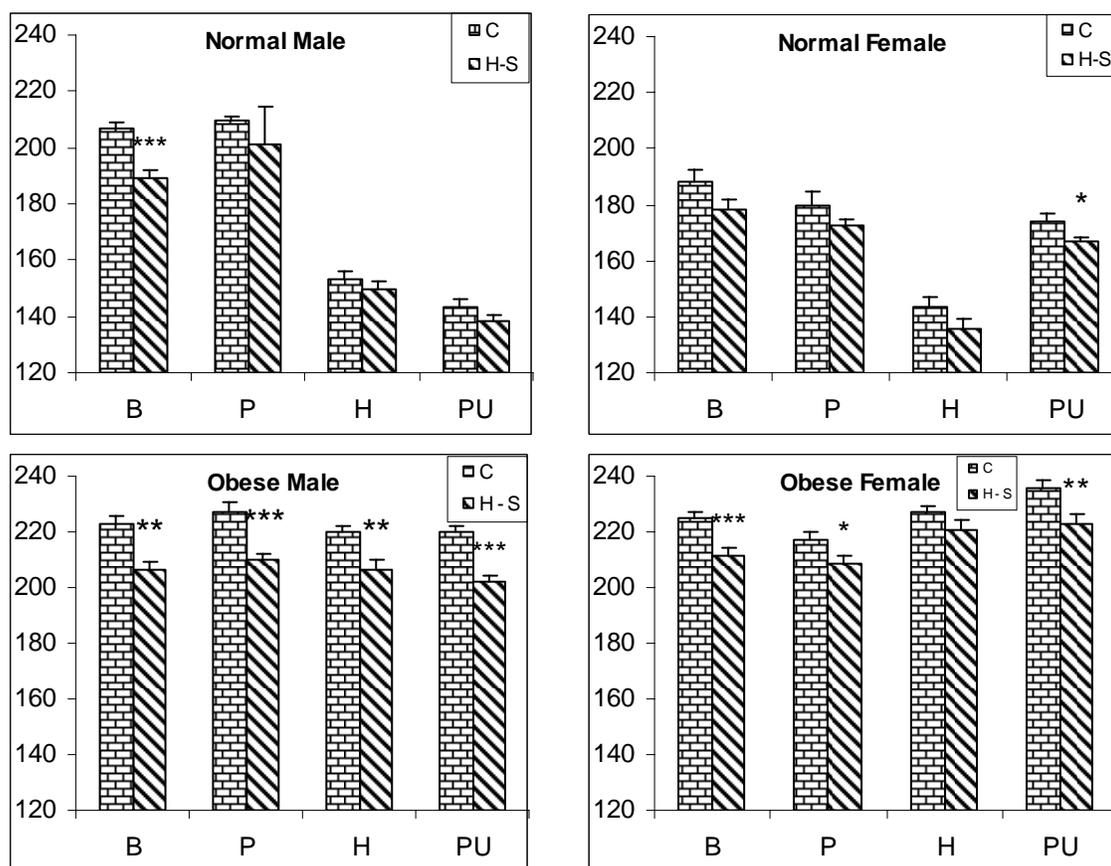


Fig. 2. Serum triglycerides mg/dl in the control (C) and obese males and females, before and after honey supplementation (H – S) in P (Pathan), B (Baloch), H (Hazara) and PU (Punjabi) ethnic groups. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

and Pathan groups exhibited statistically significant ($P < 0.022$) and ($P < 0.006$) increase in HDL level respectively.

Favorable increasing effect of honey in taking on HDL cholesterol concentration was powerfully expressed in obese of the most ethnic groups and weakly shown in a very few normal weight volunteers' group. This effect was prominent in both genders of obese as well as normal weight Baloch and Pathan subjects. May be genetic and/or life style characteristics are cause of such distinctive effect.

LDL cholesterol (Fig. 4)

Normal weight males as well as females of all ethnic groups did not show any significant effect however slight non significant reduction of the

fraction was observed in all the groups.

The values of LDL in obese males were found to be markedly higher compared to its female group. Honey consumption in obese male exhibited marked and significant ($P < 0.001$), ($P < 0.026$), ($P < 0.018$), and ($P < 0.001$) reduction in all Baloch, Pathan, Hazara and Punjabi groups respectively. In obese female, however, honey caused significant ($P < 0.001$) and ($P < 0.004$) respective reduction in LDL level in Baloch and Pathan groups only.

The significant beneficial effect of honey in take on LDL cholesterol was noticeably found to be exerted in most of the obese ethnic groups, compared to that non significant effect in normal weight volunteers. The results evidently show that the effect of honey on LDL cholesterol is powerful and specific in obese than normal weight state.

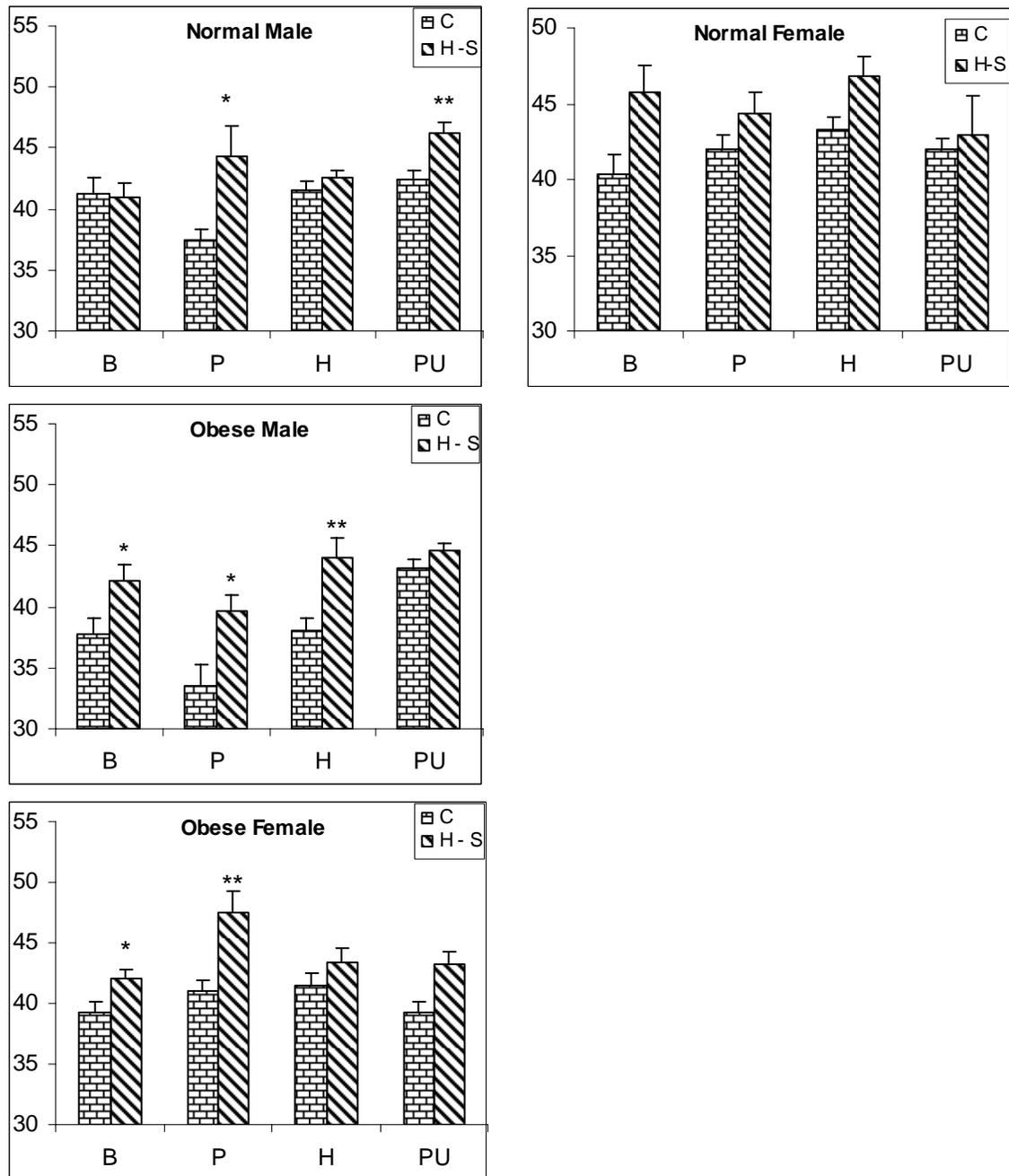


Fig. 3. Serum HDL mg/dl in the control (C) and obese males and females, before and after honey supplementation (H – S) in P (Pathan), B (Baloch), H (Hazara) and PU (Punjabi) ethnic groups. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

DISCUSSION

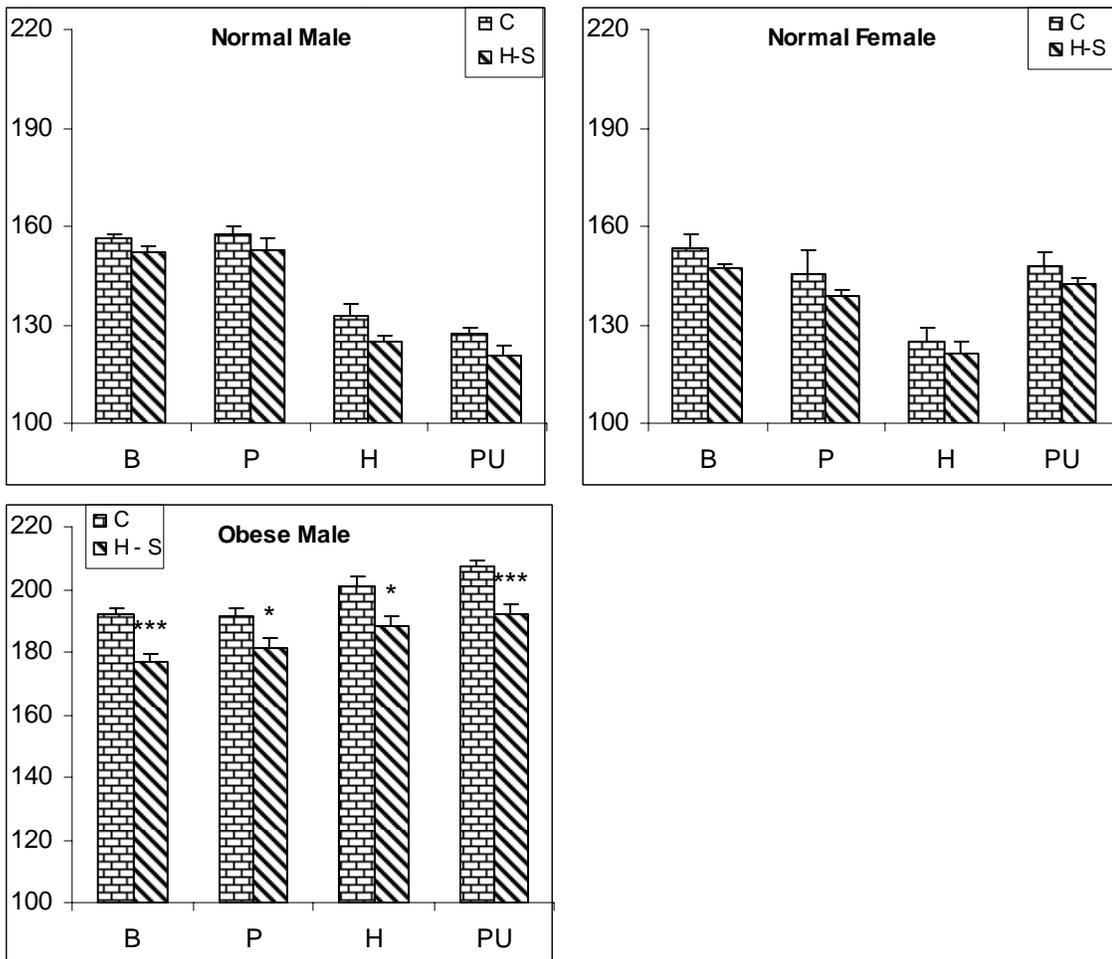
The main findings of this study are the ability of natural honey to modulate and regulate body

weight and lipid profile specifically in obese compared to the normal weight subjects which also have randomly shown the significant effect on specific parameters and differentially in a few ethnic

groups. Honey is a naturally occurring sweetener that contains a mix of both simple and complex sugars, as well as vitamins, minerals, acids and enzymes (Molan, 1996). Presently obesity has reached epidemic proportions globally, and the situation is likely to deteriorate. It is an important health problem worldwide, and its prevalence is increasing in both developed and developing nations with changes in dietary habits and activity level (Flegal *et al.*, 2005). The present study has revealed important clues of honey effecting very positively on lipid profile specifically in obese subjects as well feebly in normal weight subjects and selectively enhancing HDL cholesterol in specific ethnic

groups.

In both normal weight and obese subjects of both genders in the present study, the BMI was reduced, however, non significantly after honey consumption. Studies of Chepulis (2007) have also demonstrated that honey reduced weight gain compared with sucrose in short-term feeding. Bahrami *et al.* (2009) observed beneficial effects on body weight in 8-week consumption of honey in diabetic patients. Honey consumption did not increase body weight in overweight or obese subjects (Yaghoobi *et al.*, 2009). It may be well



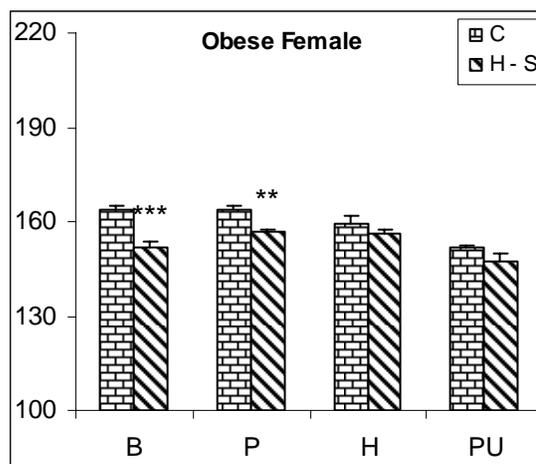


Fig. 4. Serum LDL mg/dl in the control (C) and obese males and females, before and after honey Supplementation (H – S) in P (Pathan), B (Baloch), H (Hazara) and PU (Punjabi) ethnic groups. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

accepted that consumption of honey does not increase body weight which is beneficial in case other parameters express clear benefits of the honey.

Some parameters that are important in the assessment of health in life style and directly indicators of the development of cardiovascular diseases have demonstrated improving influence against the risk to obesity from such disease situation. The study also disclosed that the subjects of different ethnic groups had responded variably to the effects of honey intake; even the gender response within an ethnic group was different in some cases. Cholesterol reducing effect of honey was mainly exhibited in both normal weight and obese subject with noticeably greater impact in the obese category. In both genders of obese Baloch and Punjabi and in males of Hazara cholesterol was reduced, however, the reduction was found in both genders of the Baloch and the males of the Pathan normal weight subjects only. There was no specific pattern in the reducing effect of honey on the cholesterol in different ethnic groups, therefore, the genetic or the life style factors may not be considered in influencing the variable response of the cholesterol following intake of honey. It may be assumed that constituents of honey may modulate the metabolism in obesity promoting lipolysis or inhibiting lipogenesis.

In obese subjects of all the ethnic groups

triglycerides were reduced in both genders except females of the Hazara subjects. In the controls, only in the male Baloch and female Punjabi it decreased significantly. Thus honey had shown striking effect in reducing triglycerides in obese subjects compared to sporadic effect in the respective controls of normal weight honey takers. Honey may be effecting this response in obese by modulating the role of enzymes in the lipid metabolism. May be honey facilitates the utilization of triglycerides or reduces their synthesis. The mobilization of fatty acids (FAs) from all fat depots depends on the activity of TG hydrolases (Zechner *et al.*, 2009) thus honey may restrain the activity of TG hydrolases.

High density lipoprotein cholesterol in obese increased in both the sexes of Baloch and Pathan and only in males of Hazara with no significant effect in Punjabi group. In normal weight subjects only the Pathan and Punjabi male subjects manifest statistically significant increase, however, in females non significant elevation was observed in all studied ethnic groups. Honey seems to raise HDL-c level by adjustments in the lipoprotein metabolism.

Prominent effect of decrease in LDL-c in obese of all the ethnic groups in both the sexes except females of Hazara and Punjabi subject was observed. Compared to that in controls no such effect had been observed. LDL-c reduction in the

larger groups of obese subjects of various ethnic groups compared to the control expound that honey also modulated the enzymatic activity in the lipid metabolism to materialize this effect, lipoprotein lipase (LPL) hydrolyzes triglyceride in chylomicrons (Goldberg, 1996). May be the reduction in lipoproteins is modulated by influencing LPL. There is possibility that honey improves the metabolism of LDL-c through its receptor at hepatic level.

There is a general trend of improvement in lipid profile and specific impact on obese subjects. The results are in agreement with Al Waili (2004b) who also reported that natural honey improved lipid profile. Also with 8-week consumption of honey beneficial effects on blood lipids of diabetic patients (Bahrami *et al.*, 2009); on LDL cholesterol only in women (Münstedt *et al.*, 2009) and in reducing cardiovascular risk factors (Yaghoobi *et al.*, 2009) were studied.

The present study have specifically identified that honey has a pivotal role in improving the lipid profile in obese subjects of the diverse ethnic groups and particularly on triglycerides and LDL components of the circulating lipids. Further studies on triglycerides and LDL are expected to reveal the mechanism in lowering these components of the lipid profile.

REFERENCES

- AL-WAILI, N.S., 1999. Glycemic response to glucose and honey in patients with diabetes mellitus. *FASEB J.* **13**: A727.
- AL-WAILI, N.S., 2003a. Effects of daily consumption of honey solution on hematological indices and blood levels of minerals and enzymes in normal individuals. *J. Med. Food*, **6**: 135-140.
- AL-WAILI, N.S., 2003b. Intrapulmonary administration of natural honey solution, hyperosmolar dextrose or hypoosmolar distill water to normal individuals and to patients with type-2 diabetes mellitus or hypertension: their effects on blood glucose level, plasma insulin and C-peptide, blood pressure and peaked expiratory flow rate. *Eur. J. Med. Res.*, **8**: 295-303.
- AL-WAILI, N.S., 2004a. Investigating the antimicrobial activity of natural honey and its effects on the pathogenic bacterial infections of surgical wounds and conjunctiva. *J. Med. Food*, **7**: 210-222.
- AL-WAILI, N.S., 2004b. Topical honey application vs. acyclovir for the treatment of recurrent herpes simplex lesions. *Int. Med. J. Experi. Clin. Res.*, **10**: M94-98.
- AL-WAILI, N.S., 2004c. Natural honey lowers plasma glucose, C-reactive protein, homocysteine, and blood lipids in healthy, diabetic, and hyperlipidemic subjects: comparison with dextrose and sucrose. *J. Med. Food*, **7**: 100-107.
- AL-WAILI, N.S. AND BONI, N.S., 2003. Natural honey lowers plasma prostaglandin concentrations in normal individuals. *J. Med. Food*, **6**: 129-133.
- AL-WAILI, N.S. AND HAQ, A., 2004. Effect of honey on antibody production against thymus-dependent and thymus-independent antigens in primary and secondary immune responses. *J. Med. Food*, **7**: 491-494.
- AL-WAILI, N.S. AND SALOOM, K.Y., 1999. Effects of topical honey on post-operative wound infections due to gram positive and gram negative bacteria following caesarean sections and hysterectomies. *Euro. J. Med. Res.*, **4**: 126-130.
- BAHRAMI, M., ATAIE-JAFARI, A., HOSSEINI, S., FORUZANFAR, M.H., RAHMANI, M. AND PAJOUHI, M., 2009. Effects of natural honey consumption in diabetic patients: an 8-week randomized clinical trial. *Int J Food Sci Nutr.*, **60**: 618-626.
- BEJAN, V., LACATIS, D., PETRUS, V., BEJAN, V.V. AND CRETEANU, G., 1978. L'emploi Du fructose dans le regime du diabete sucre insulino-dependant. *IIIe Symposium International d'Apitherapie*, 11-15 Septembre 1978, Portoroz, Yougoslavie. Bukarest: Apimondia, 382-384.
- BORNET, F., HAARDT, M., COSTAGLIOLA, D., BLAYO, A. AND SLAMA, G., 1985. Sucrose or honey at breakfast have no additional acute hyperglycaemic effect over an isoglucic amount of bread in Type 2 diabetic patients. *Diabetologia*, **28**: 213-217.
- CHEPULIS, L., 2007. The effect of honey compared to sucrose, mixed sugars and a sugar free diet or weight gain in young rats. *J. Food Sci.*, **7**: 224-229.
- FLEGAL, K.M., GRAUBARD, B.I., WILLIAMSON, D.F. AND GAIL, M.H., 2005. Excess deaths associated with underweights, overweights, and obesity. *JAMA*, **293**: 1861-1867.
- GOLDBERG, I.J., 1996. Lipoprotein lipase and lipolysis: central roles in lipoprotein metabolism and atherogenesis. *J. Lipid Res.*, **37**: 693-707.
- KATSILAMBROS, N.L., PHILIPPIDES, P., TOULIATOU, A., GEORGAKOPOULOS, K., KOFOTZOULI, L., FRANGAKI, D., SISKOUDIS, P., MARANGOS, M. AND SFIKAKIS, P., 1988. Metabolic effects of honey (alone or combined with other foods) in type II diabetics. *Acta Diabetol. Lat.*, **25**: 197-203.
- MOLAN, P., 1996. Authenticity of honey. In: *Food authentication* (eds. P.R. Ashurst and M.J. Dennis), Blackie Academic and Professional, London, pp. 259-303.

- MÜNSTEDT, K., HOFFMANN, S., HAUENSCHILD, A., BÜLTE, M., VON GEORGI, R. AND HACKETHAL, A., 2009. Effect of honey on serum cholesterol and lipid values. *J Med Food*, **12**: 624-628.
- PERETTI, A., CARBINI, L., DAZZI, E., PITTAU, L., SPANU, P. AND MANAI, M., 1994. Uso razionale del miele nell'alimentazione dei diabetici. *Clin. Dietolog.* **21**:13-21.
- WHO, 1998. Obesity: Preventing and managing the global epidemic. WHO: Geneva; 1998.
- YAGHOobi, N., AL-WAILI, N., GHAYOUR-MOBARHAN, M., PARIZADEH, S.M., ABASALTI, Z., YAGHOobi, Z., YAGHOobi, F., ESMAEILI, H., KAZEMI-BAJESTANI, S.M., AGHASIZADEH, R., SALOOM, K.Y. AND FERNS, G.A., 2009. Natural honey and cardiovascular risk factors; effects on blood glucose, cholesterol, triacylglycerole, CRP, and body weight compared with sucrose. *Scientific World J.*, **8**: 463-469.
- ZECHNER, R., KIENESBERGER, P.C., HAEMMERLE, G., ZIMMERMANN, R. AND LASS, A., 2009. Adipose triglyceride lipase and the lipolytic catabolism of cellular fat stores. *J. Lipid Res.*, **50**, 3-21.

(Received 27 September 2009, revised 8 October 2010)