

An Integral Involving Certain General Class of Polynomials and the Special Functions

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Abstract: The object of present paper is to establish an integral pertaining to a product of Fox's H-function, general polynomials given by Srivastava and H-function of several complex variables given by Srivastava and Panda with general arguments of quadratic nature.

I. Introduction

(a). The H-function of several complex variables is defined by Srivastava and Panda as:

$$H[p_1, \dots, p_r] = H_{A+1, C+1; [B', D']; \dots; [B^{(r)}, D^{(r)}]}^{0, \lambda+1; (u^{(1)}, v^{(1)}); \dots; (u^{(r)}, v^{(r)})} \left[\begin{matrix} [(\beta_1)^{(1)}; \theta^{(1)}; \dots; \theta^{(r)}]; [(\beta_2^{(1)}); \phi]; \dots; [(\beta_2^{(r)}); \phi^{(r)}]; \\ (\beta_3); \psi; \dots; \psi^{(r)}; [(\beta_1)^{(1)}; \delta]; \dots; [(\beta_4^{(r)}); \rho^{(r)}]; \end{matrix} \right. p_1, \dots, p_r \left. \right] \dots(1.1)$$

(b). The series representation of Fox's H-function is given by

$$H_{P, Q}^{M, N} \left[p \left| \begin{matrix} (e_P, F_P) \\ (f_Q, F_Q) \end{matrix} \right. \right] = \sum_{G=0}^{\infty} \sum_{g=1}^M \frac{(-1)^G}{G! F_g} \xi(\rho_G) Z^{\rho_G}$$

where

$$\xi(\rho_G) = \frac{\prod_{\substack{j=1 \\ j \neq g}}^M \Gamma(f_j - F_j \rho_G) \prod_{j=1}^N \Gamma(1 - e_j + E_j \rho_G)}{\prod_{j=M+1}^Q \Gamma(1 - f_j + F_j \rho_G) \prod_{j=N+1}^P \Gamma(e_j - E_j \rho_G)} \dots(1.2)$$

and

$$\delta_G = \left(\frac{f_j + G}{F_g} \right)$$

(c). Srivastava has defined and introduced the general polynomials as

$$S_{N_1, \dots, N_s}^{M_1, \dots, M_s} [w_1, \dots, w_s] = \sum_{\mu_1=0}^{[N_1/M_1]} \dots \sum_{\mu_s=0}^{[N_s/M_s]} \frac{(-N_1)_{M_1 \mu_1}}{\mu_1!} \dots \frac{(-N_s)_{M_s \mu_s}}{\mu_s!} \cdot A [N_1, \mu_1; \dots; N_s, \mu_s] w_1^{\mu_1} \dots w_s^{\mu_s} \dots(1.3)$$

where $N_i = 0, 1, 2, \dots, \forall i (1, \dots, s), M_1, \dots, M_s$ are arbitrary positive integers and the coefficients

$A [N_1, \mu_1; \dots; N_s, \mu_s]$ are arbitrary constants, real or complex.

(d). A general class of multivariable polynomial defined and represented by Srivastava and Garg, is given in the following manner

$$S_V^{W_1, \dots, W_s} [a_1, \dots, a_s] = \sum_{k_1, \dots, k_\ell=0}^{W_1 k_1 + \dots + W_\ell k_\ell} (-V)_{W_1 k_1 + \dots + W_\ell k_\ell} A(V; k_1, \dots, k_\ell) \frac{y_1^{k_1}}{k_1!}, \dots, \frac{(y_s)^{k_\ell}}{k_\ell!} \dots(1.4)$$

II. The Main Result

The following integral has been established in this paper

$$\int_0^\infty x^{1-\mu} (\beta_1 + \beta_2 x + \beta_3 x^2)^{\mu-3/2} H_{P,Q}^{M,N} \left[\left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^v \middle| \begin{matrix} (e_P, E_P) \\ (f_Q, F_Q) \end{matrix} \right] \cdot S_{N_1, \dots, N_s}^{M_1, \dots, M_s} \left[v_1 \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{d_1}, \dots, v_s \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{d_s} \right] \cdot S_V^{W_1, \dots, W_\ell} \left[y_1 \left(\frac{x}{\beta_1 + \beta_2 + \beta_3 x^2} \right)^{m_1}, \dots, y_\ell \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{m_\ell} \right] \cdot H \left[p_1 \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{v_1}, \dots, p_r \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{v_r} \right] dx = \sqrt{\frac{\pi}{\beta_3}} \sum_{G=0}^\infty \sum_{g=1}^m \sum_{\mu_1=0}^{[N_1/M_1]} \dots \sum_{\mu_s=0}^{[N_s/M_s]} \frac{(-1)^G}{G! F_g} \frac{(-N_1)_{M_1 \mu_1}}{\mu_1!} \dots \frac{(-N_s)_{M_s \mu_s}}{\mu_s!} \xi(\rho_G) \cdot A[N_1 \mu_1; \dots; N_s \mu_s] v_1^{\mu_1}, \dots, v_s^{\mu_s} A(V; k_1, \dots, k_\ell) \cdot (\beta_2 + \sqrt{\beta_1 \beta_3})^{\left(\mu - v \rho_G - \sum_{i=1}^s d_i \mu_i - \sum_{i=1}^\ell m_i k_i - 1 \right)} H_{A+1, C+1; [B^{(1)}, D^{(1)}]; \dots; [B^{(r)}, D^{(r)}]}^{0, \lambda+1; (u^{(1)}, v^{(1)}); \dots; (u^{(r)}, v^{(r)})} \left[\begin{matrix} \left(\mu - v \rho_G - \sum_{i=1}^s d_i \mu_i - \sum_{i=1}^\ell m_i k_i; (v_1, \dots, v_r) \right) \\ [(\beta_1); \theta^{(1)}; \dots; \theta^{(r)}]; [(\beta_2^{(1)}); \xi^{(1)}]; \dots; [(\beta_2^{(r)}); \xi^{(r)}] \end{matrix} \right] \cdot [(\beta_3); \xi^{(1)}, \dots, \xi^{(r)}] \left[\mu - v \rho_G - \sum_{i=1}^s d_i \mu_i - \sum_{i=1}^\ell m_i k_i - 1/2; v_1, \dots, v_r \right]; [(\beta_4^{(1)}); \delta^{(1)}]; \dots; [(\beta_4^{(r)}); \delta^{(r)}]; p_1 (\beta_2 + 2\sqrt{\beta_1 \beta_3})^{-v_1}, \dots, p_r (\beta_2 + 2\sqrt{\beta_1 \beta_3})^{-v_r} \dots(2.1)$$

Proof

In order to prove the given integral, we express the Fox’s H-function and a general polynomials in the form of series and the H-function of several complex variables in terms of Mellin-Barnes contour integrals. Now interchanging the order of summations and integrations which is permissible under the stated conditions, we obtain

$$\begin{aligned}
 & \sum_{G=0}^{\infty} \sum_{g=1}^M \sum_{\mu_1=0}^{[N_1/M_1]} \dots \sum_{\mu_s=0}^{[N_s/M_s]} \frac{(-1)^G (-N_1)_{M_1 \mu_1}}{\mu_1!} \dots \frac{(-N_s)_{M_s \mu_s}}{\mu_s!} \xi(\rho_G) \\
 & \cdot A[N_1 \mu_1; \dots; N_s \mu_s] v_1^{\mu_1}, \dots, v_s^{\mu_s} A(V; k_1, \dots, k_\ell) \\
 & \cdot \frac{1}{(2\pi i)^\mu} \int_{L_1} \dots \int_{L_r} \psi(e_1, \dots, e_r) \theta(e_1) \dots \theta(e_r) p_1^{e_1} \dots p_r^{e_r} \\
 & \cdot \left\{ \int_0^\infty x^{1-\mu} \left(\mu - v \rho_n - \sum_{i=1}^s d_i \mu_i - \sum_{i=1}^\ell m_i k_i - v e_1 \dots v_r e_r \right) \right. \\
 & \left. (\beta_1 + \beta_2 + \beta_3 x^2)^{\left(\mu - v \rho_G - \sum_{i=1}^s d_i \mu_i - \sum_{i=1}^\ell m_i h_i - v e_1 \dots v_r e_r \right)^{-3/2}} dx de_1 \dots de_r \right\} \dots (2.2)
 \end{aligned}$$

Evaluating the above integral with the help of known theorem and reinterpreting the result in terms of H-function of r-variables, we arrive at desired result.

III. Numerical Results

(a) Taking $\lambda = A, u^{(i)} = 1, v^{(i)} = B^{(i)}$ and $D^{(i)} = D^{(i)} + 1, \forall i \in (1, \dots, r)$, the result reduces to following integral transformation

$$\begin{aligned}
 & \int_0^\infty x^{1-\mu} (\beta_1 + \beta_2 x + \beta_3 x^2)^{\mu-3/2} H_{P,Q}^{M,N} \left[\left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^v \middle| \begin{matrix} (e_P, E_P) \\ (f_Q, F_Q) \end{matrix} \right] \\
 & \cdot S_{N_1, \dots, N_s}^{M_1, \dots, M_s} \left[v_1 \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{d_1}, \dots, v_s \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{d_s} \right] \\
 & S_V^{W_1, \dots, W_\ell} \left[y_1 \left(\frac{x}{\beta_1 + \beta_2 + \beta_3 x^2} \right)^{m_1}, \dots, y_\ell \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{m_\ell} \right] \\
 & F_{C:D^{(1)}, \dots, D^{(r)}}^{A:B^{(1)}, \dots, B^{(r)}} \left[-p_1 \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{v_1}, \dots, -p_r \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{v_r} \right] \\
 & \cdot \left[\begin{matrix} [1-(\beta_1):\theta^{(1)}, \dots, \theta^{(r)}]:[1-(\beta_2^{(1)}):\gamma^{(1)}]; \dots; [1-(\beta_2^{(r)}):\gamma^{(r)}] \\ [1-(\beta_3):\psi^{(1)}; \dots, \psi^{(r)}]:[1-(\beta_4^{(1)}):\delta]; \dots; [1-(\beta_4^{(r)}):\delta^{(r)}] \end{matrix} \right] dx \\
 & = \sqrt{\frac{\pi}{\beta_3}} \sum_{G=0}^{\infty} \sum_{g=1}^m \sum_{\mu_1=0}^{[N_1/M_1]} \dots \sum_{\mu_s=0}^{[N_s/M_s]} \frac{(-1)^G}{G! F_g} \frac{(-N_1)_{M_1 \mu_1}}{\mu_1!} \dots \frac{(-N_s)_{M_s \mu_s}}{\mu_s!} \xi(\rho_G)
 \end{aligned}$$

$$\begin{aligned}
 & \cdot A[N_1\mu_1; \dots; N_s\mu_s] v_1^{\mu_1}, \dots, v_s^{\mu_s} A(V; k_1, \dots, k_\ell) \\
 & \cdot (\beta_2 + \sqrt{\beta_1\beta_3})^{\left(\mu - \nu\rho_G - \sum_{i=1}^s d_i\mu_i - \sum_{i=1}^{\ell} m_i k_i - 1\right)} \\
 & \frac{\Gamma\left(1 - \mu + \nu\rho_G + \sum_{i=1}^s d_i\mu_i + \sum_{i=1}^{\ell} m_i k_i\right)}{\Gamma\left(3/2 - m + \nu\rho_G + \sum_{i=1}^s d_i\mu_i + \sum_{i=1}^{\ell} m_i k_i\right)} F_{C+1; D^{(1)}, \dots, D^{(r)}}^{A+1; B^{(1)}, \dots, B^{(r)}} \\
 & [-p_1(\beta_2 + 2\sqrt{\beta_1\beta_3})^{-\nu_1}, \dots, -p_r(\beta_2 + 2\sqrt{\beta_1\beta_3})^{-\nu_r}] \\
 & \left[1 - \mu + \gamma\rho_G + \sum_{i=1}^s d_i\mu_i + \sum_{i=1}^{\ell} m_i k_i; \nu_1; \dots; \nu_r\right] [1 - (\beta_1); \theta^{(1)}; \dots; \theta^{(r)}] \\
 & [1 - (\beta_3) : \psi^{(1)}; \dots; \psi^{(r)}], \left[3/2 - \mu + \nu\rho_G + \sum_{i=1}^s d_i\mu_i + \sum_{i=1}^{\ell} m_i k_i : \nu_1; \dots; \nu_r\right] : \\
 & [1 - (\beta_2^{(1)}) : \gamma^{(1)}; \dots; [1 - (\beta_2^{(r)}) : \gamma^{(r)}] \\
 & [1 - (\beta_4^{(1)}) : \delta^{(1)}; \dots; [1 - (\beta_4^{(r)}) : \delta^{(r)}] \dots(3a)
 \end{aligned}$$

provided that $\text{Re}(\beta_1) > 0, \text{Re}(\beta_2) > 0, \beta_3 > 0$, the series on right side exist.

(b) Taking $\theta^{(1)}, \dots, \theta^{(r)} = \gamma^{(1)}, \dots, \gamma^{(r)} = \psi^{(1)}, \dots, \psi^{(r)} = \delta^{(1)}, \dots, \delta^{(r)} = \nu_1, \dots, \nu_r = \mu^{(1)}, \dots, \mu^{(r)}$ in equation (2.1), we get the following integral transformation

$$\begin{aligned}
 & \int_0^\infty x^{1-\mu} (\beta_1 + \beta_2 x + \beta_3 x^2)^{\mu-3/2} H_{P,Q}^{M,N} \left[\left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^v \middle| \begin{matrix} (e_P, E_P) \\ (f_Q, F_Q) \end{matrix} \right] \\
 & \cdot S_{N_1, \dots, N_s}^{M_1, \dots, M_s} \left[v_1 \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{d_1}, \dots, v_s \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{d_s} \right] \\
 & S_V^{W_1, \dots, W_\ell} \left[y_1 \left(\frac{x}{\beta_1 + \beta_2 + \beta_3 x^2} \right)^{m_1}, \dots, y_\ell \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{m_\ell} \right] \\
 & G_{A; C; [B^{(1)}, D^{(1)}]; \dots; [B^{(r)}, D^{(r)}]}^{0, \lambda; (u^{(1)}, v^{(1)}); \dots; (u^{(r)}, v^{(r)})} \\
 & \cdot \left[p_1^{\mu^{(1)}} \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right), \dots, p_r^{\mu^{(r)}} \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right) \middle| \begin{matrix} (\beta_1); (\beta_2^{(1)}); \dots; (\beta_2^{(r)}) \\ (\beta_3); (\beta_4^{(1)}); \dots; (\beta_4^{(r)}) \end{matrix} \right] dx
 \end{aligned}$$

$$\begin{aligned}
 &= \sqrt{\frac{\pi}{\beta_3}} \sum_{G=0}^{\infty} \sum_{g=1}^M \sum_{\mu_1=0}^{[N_1/M_1]} \cdots \sum_{\mu_s=0}^{[N_s/M_s]} \frac{(-1)^G}{G! F_g} \frac{(-N_1)_{M_1 \mu_1}}{\mu_1!} \cdots \frac{(-N_s)_{M_s \mu_s}}{\mu_s!} \xi(\rho_G) \\
 &\quad \cdot A[N_1 \mu_1; \dots; N_s \mu_s] v_1^{\mu_1}, \dots, v_s^{\mu_s} A(V; k_1, \dots, k_\ell) \\
 &\quad \cdot (\beta_2 + \sqrt{\beta_1 \beta_3})^{\left(\mu - \nu \rho_G - \sum_{i=1}^s d_i \mu_i - \sum_{i=1}^{\ell} m_i k_i - 1 \right)} \\
 &\quad \mathbf{G}^{0, \lambda: (u^{(1)}, v^{(1)}); \dots; (u^{(r)}, v^{(r)})} \\
 &\quad \mathbf{A: C: [B^{(1)}, D^{(1)}]; \dots; [B^{(r)}, D^{(r)}]} \\
 &\quad \cdot \left[p_1^{\frac{1}{\mu^{(1)}}} (\beta_2 + 2\sqrt{\beta_1 \beta_3})^{-1}, \dots, p_r^{\frac{1}{\mu^{(r)}}} (\beta_2 + 2\sqrt{\beta_1 \beta_3})^{-1} \right] \\
 &\quad \left(\mu + \nu \rho_G + \sum_{i=1}^s d_i \mu_i + \sum_{i=1}^{\ell} m_i k_i - 1 \right), (\beta_1) : (\beta_2^{(1)}); \dots; \beta_2^{(r)} \\
 &\quad (\beta_3), \left(\mu - \nu \rho_G + \sum_{i=1}^s d_i \mu_i + \sum_{i=1}^{\ell} m_i k_i - 1/2 \right) : (\beta_4^{(1)}); \dots; (\beta_4^{(r)}) \quad \dots(3b)
 \end{aligned}$$

provided that $\text{Re}(\beta_1) > 0, \text{Re}(\beta_2) > 0, \beta_3 > 0; \mu^{(i)} > 0 (i = 1, \dots, r), 2(u^{(i)} + v^{(i)}) > (A + C + B^{(i)} + D^{(i)})$,

$$|\arg(z_i)| < \left[u^{(i)} + v^{(i)} - \frac{A}{2} - \frac{C}{2} - \frac{B^{(i)}}{2} - \frac{D^{(i)}}{2} \right] \pi \text{ and}$$

$$v \left\{ \min_{1 \leq j \leq M} [\text{Re}(f_j / F_j)] \right\} + \sum_{i=1}^r \left\{ \min_{1 \leq j \leq u^{(i)}} [\text{Re}(d_j^{(i)})] \right\} > \mu^{-2}.$$

(c) When $\lambda = A = C = 0$ in (2.1), we have the following transformation:

$$\begin{aligned}
 &\int_0^\infty x^{1-\mu} (\beta_1 + \beta_2 x + \beta_3 x^2)^{\mu-3/2} \mathbf{H}_{P,Q}^{M,N} \left[\left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^v \middle| \begin{matrix} (\epsilon_P, E_P) \\ (f_Q, F_Q) \end{matrix} \right] \\
 &\quad \cdot \mathbf{S}_{N_1, \dots, N_s}^{M_1, \dots, M_s} \left[v_1 \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{d_1}, \dots, v_s \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{d_s} \right] \\
 &\quad \mathbf{S}_V^{W_1, \dots, W_\ell} \left[y_1 \left(\frac{x}{\beta_1 + \beta_2 + \beta_3 x^2} \right)^{m_1}, \dots, y_\ell \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{m_\ell} \right]
 \end{aligned}$$

$$\prod_{i=1}^r H_{B^{(i)}, D^{(i)}}^{u^{(i)}, v^{(i)}} \left[P_i \left(\frac{x}{\beta_1 + \beta_2 x + \beta_3 x^2} \right)^{v_i} \middle| \begin{matrix} \beta_2^{(i)}; \gamma^{(i)} \\ [d^{(i)}; \delta^{(i)}] \end{matrix} \right] dx$$

$$= \sqrt{\frac{\pi}{\beta_3}} \sum_{G=0}^{\infty} \sum_{g=1}^M \sum_{\mu_1=0}^{[N_1/M_1]} \dots \sum_{\mu_s=0}^{[N_s/M_s]} \frac{(-1)^G}{G! F_g} \frac{(-N_1)_{M_1 \mu_1}}{\mu_1!} \dots \frac{(-N_s)_{m_1 \alpha_1}}{\alpha_1!} \frac{(-n_s)_{M_s \mu_s}}{\mu_s!} \xi(\rho_G)$$

$$A[N_1, \mu_1; \dots; N_s, \mu_s] v_1^{\mu_1} \dots v_s^{\mu_s} A[V; k_1, \dots, k_\ell]$$

$$\cdot (\beta_2 + 2\sqrt{\beta_1 \beta_3})^{\left(\mu - v \rho_G - \sum_{i=1}^s d_i \mu_i - \sum_{i=1}^{\ell} m_i k_i - 1 \right)}$$

$$\cdot H_{1, [B^{(1)}, D^{(1)}]; \dots; [B^{(r)}, D^{(r)}]}^{0, [u^{(1)}, v^{(1)}]; \dots; [u^{(r)}, v^{(r)}]} \left[\begin{matrix} p_1 (\beta_2 + 2\sqrt{\beta_1 \beta_3})^{-v_1} \\ \vdots \\ p_r (\beta_2 + 2\sqrt{\beta_1 \beta_3})^{-v_r} \end{matrix} \right]$$

$$\left[\begin{matrix} \left[\mu - v \rho_G - \sum_{i=1}^s d_i \mu_i - \sum_{i=1}^{\ell} m_i k_i; v_1; \dots; v_r \right]; [(\beta_2^{(1)}); \gamma^{(1)}]; \dots; [(\beta_2^{(r)}); \gamma^{(r)}] \\ \left[\mu - v \rho_G - \sum_{i=1}^s d_i \mu_i - \sum_{i=1}^{\ell} m_i k_i - 1/2; v_1; \dots; v_r \right]; [(\beta_4^{(1)}); \delta^{(1)}]; \dots; [(\beta_4^{(r)}); \delta^{(r)}] \end{matrix} \right] \dots (3c)$$

valid under same conditions as obtained from (2.1).

- (d) Replacing N_1, \dots, N_s by N and $V \rightarrow 0$, the result in (2.1) reduces to known result in [2] after little simplification.
- (e) Taking $N_i \rightarrow 0 (i = 1, \dots, s), V \rightarrow 0, \beta_1 = 0, \beta_3 = 1$, the result in (2.1) reduces to known result after little simplification obtained by Goyal and Mathur [4].
- (f) If $r = 1$, and $M_i, N_i \rightarrow 0 (i = 2, \dots, s)$ and $V \rightarrow 0$, the result in (2.1) reduces to known result with little modification recently derived by Gupta and Jain [5].
- (g) Taking $V \rightarrow 0$, the result in (2.1) reduces to known result after littler simplification obtained by Chaurasia and Shekhawat [2].

IV. Conclusion

The integral thus obtained is believed to be one of the most general integral established so far. The findings of this paper are sufficiently general in nature and are capable of yielding numerous (known or new) results involving classical orthogonal polynomials hitherto scattered in the literature.

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