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# CERTAIN RESULTS INVOLVING POLYBASIC HYPERGEOMETRIC FUNCTIONS AND INFINITE PRODUCTS

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***Abstract :*** *In this paper , making use of certain Polybasic hypergeometric functions and infinite products, an attempt has been made to establish results involving polybasic hypergeometric functions and infinite products.*

***Keywords :*** *Polybasic hypergeometric functions, infinite products, summations formulae, truncated series.*

## 1. Introduction

In 2011 Srivastava et. al. [4] by making use of Bailey's transformation of truncated series, have established transformation formulae involving polybasic hypergeometric functions.

## 2. Notations

In this section , we list some standard summation and transformation formulae for the basic hypergeometric series which are used in this paper.
Assuming that $|q| < 1$ , where q- is non-zero complex number, this condition ensures that all the infinite product will converge.

$$(a;q)_n = (a,q)_n = \begin{cases} 1 \ ; n=0 \\ (1-a)(1-aq)\ldots\ldots(1-aq^{n-1}) \quad ; n = 1,2,3\ldots\ldots \end{cases} \tag{2.1}$$

$$(a_1, a_2, a_3 \ldots\ldots a_r; q)_n = (a_1;q)_n (a_2;q)_n (a_3;q)_n \ldots\ldots (a_r;q)_n \tag{2.2}$$

$$(a;q)_{-n} = \frac{\left(-\frac{q}{a}\right)^n q^{\frac{n(n-1)}{2}}}{\left(\frac{q}{a};q\right)_n} (a;q)_n \tag{2.3}$$

$$(a;q)_{2n} = (a;q^2)_n (aq;q^2)_n \tag{2.4}$$

$$(a;q)_n = \frac{(a;q)_\infty}{(aq^n;q)_\infty} \tag{2.5}$$

$$(a;q)_\infty = \prod_{r=0}^{\infty} (1-aq^r) \tag{2.6}$$

The polybasic hypergeometric series is defined,

$$\Phi\begin{bmatrix} a_1, a_2, \ldots, a_r : c_{1,1}, \ldots c_1, r_1; \ldots ; c_{rq,1,} \ldots c_{m,r_m}; q, q_1, \ldots q_m; z \\ b_1, b_2, \ldots, b_{r-1} : d_{1,1,} \ldots d_{1,r_1}; \ldots d_{m,1}, \ldots, d_{m,r_m} \end{bmatrix}$$

$$= \sum_{n=0}^{\infty} \frac{(a_1, a_2, \ldots, a_r; q)_n z^n}{(q, b_1, b_2, \ldots, b_{r-1}; q)_n} \prod_{j=1}^{m} \frac{(c_{j,1}, \ldots, c_{j,r_j}; q_j)_n}{(d_{j,1}, \ldots, d_{j,r_j};)_n} \tag{2.7}$$

A truncated basic hypergeometric series is

$${}_{r}\Phi_{s}\begin{bmatrix} a_1, a_2, a_3 \dots a_r; q; z \\ b_1, b_2, b_3 \dots b_s \end{bmatrix}_N = \sum_{n=0}^{N} \frac{[a_1,a_2,a_3 \dots a_r;q]_n z^n}{[b_1,b_2,b_3 \dots b_s;q]_n} \qquad (2.8)$$

where , max $(|q|, |z| < 1)$ *and* no zero appears in the denominator.

The other notations appearing in this paper have their usual meaning. We shall use the following summation formulae in our analysis.

Slater [3]

$${}_2\phi_1\begin{pmatrix} a,y,q;q \\ ayq \end{pmatrix}_n = \frac{[aq,yq;q]_n}{[q,ayq;q]_n} \qquad (2.9)$$

Agarwal [1]

$${}_4\phi_3\begin{pmatrix} \alpha,q\sqrt{\alpha},-q\sqrt{\alpha},e;q;{}^{1}/_{e} \\ q,\sqrt{\alpha},-\sqrt{\alpha},{}^{\alpha q}/_{e} \end{pmatrix}_n = \frac{(\alpha q,eq;q)_n}{(q,{}^{\alpha q}/_{e};q)_n e^n} \qquad (2.10)$$

Gasper and Rahman [2]

$${}_6\Phi_5\left[\begin{matrix} \alpha,q\sqrt{\alpha}-q\sqrt{\alpha},\beta,\gamma,\delta; \\ \sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta},\frac{\beta q}{\gamma},\frac{\gamma q}{\delta} \end{matrix}\ q,q\right]_n = \frac{(\alpha q,\beta q,\gamma q,\delta q;q)_n}{(q,\frac{\alpha q}{\beta},\frac{\alpha q}{\gamma},\frac{\alpha q}{\delta};q)_n} \quad \text{provided } \alpha = \beta\gamma\delta \qquad (2.11)$$

Gasper and Rahman [2]

$$\sum_{r=0}^{n} \frac{(1-ap^r)q^r(1-bp^r q^{-r})(c,\frac{a}{bc};q)_r q^r}{(1-a)(1-b)(q,\frac{aq}{b};q)_r(\frac{ap}{c},bcp;p)_r} = \frac{(ap,bp;p)_n(cq,\frac{aq}{bc};q)_n}{(q,\frac{aq}{b};q)_n(\frac{ap}{c},bcp;p)_n} \qquad (2.12)$$

In 1966 Slater established the following simple but very useful Bailey transformation in the form, if

$$\beta_n = \sum_{r=0}^{\infty} \alpha_r \ u_{n-r} v_{n+r} \qquad (2.13)$$

$$\gamma_n = \sum_{r=0}^{\infty} \delta_{r+n} u_r v_{2n+r} \qquad (2.14)$$

Where $\alpha_r, \delta_r, u_r, v_r$ are functions of r alone and the series for $\gamma_n$ is convergent.

## 3. Main results

$$\Phi\begin{bmatrix} \alpha, y; \alpha q; \beta q; p, q; p \\ ayp; q, \alpha\beta q \end{bmatrix} - \Phi\begin{bmatrix} \alpha, \beta; a, y; q, p; pq \\ \alpha\beta q; p, ayp \end{bmatrix}$$

$$+ \Phi\begin{bmatrix} \alpha, \beta; ap, yp; q, p; q \\ \alpha\beta q; p, ayp \end{bmatrix} = \left[\frac{(\alpha q,\beta q;q)_\infty}{(q,\alpha\beta q;q)_\infty}\right]\left[\frac{(ap,yp;p)_\infty}{(p,ayp;p)_\infty}\right] \qquad (3.1)$$

$$\Phi\begin{bmatrix} \alpha q, \beta q; a, y; q, p; p\beta \\ \frac{\alpha q}{\beta}; p, ayp \end{bmatrix} + \Phi\begin{bmatrix} \alpha, q\sqrt{\alpha}, -q\sqrt{\alpha}, \beta; ap, yp; q, p; q\beta \\ \sqrt{\alpha}, -\sqrt{\alpha}, \frac{\alpha q}{\beta}; p, ayp \end{bmatrix} - \Phi\begin{bmatrix} \alpha, q\sqrt{\alpha}, -q\sqrt{\mathrm{\tilde{a}}}, \beta; a, y; \beta p \\ \sqrt{\alpha}, -\sqrt{\alpha}, \frac{\alpha q}{\beta}; p, ayp \end{bmatrix}$$

$$= \left[\frac{(ap,yp;p)_\infty}{(p,ayp;p)_\infty}\right] \sum_{n=0}^{\infty} \frac{(\alpha,q\sqrt{\alpha},-q\sqrt{\alpha},\beta;q)_n}{(q,\sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta};q)_n} \beta^n \qquad (3.2)$$

$$\Phi\begin{bmatrix}\alpha q,\beta q,\gamma q,\delta q;a,y; & \\ \frac{\alpha q}{\beta},\frac{\alpha q}{\gamma},\frac{\alpha q}{\delta};p,ayp; & q,p;p\end{bmatrix}+\Phi\begin{bmatrix}\alpha,q\sqrt{\alpha},-q\sqrt{\alpha},\beta,\gamma,\delta;a,y; & \\ q,\sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta},\frac{\alpha q}{\gamma},\frac{\alpha q}{\delta};p,ayp; & q,p;p\end{bmatrix}$$

$$-\Phi\begin{bmatrix}\alpha,q\sqrt{\alpha},-q\sqrt{\alpha},\beta,\gamma,\delta;a,y;q,p;qp\\ q,\sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta},\frac{\alpha q}{\gamma},\frac{\alpha q}{\delta};p,ayp\end{bmatrix}=\left[\frac{(\alpha q,\beta q,\gamma q,\delta q;q)_\infty}{(q,\frac{\alpha q}{\beta},\frac{\alpha q}{\gamma},\frac{\alpha q}{\delta};q)_\infty}\right]\left[\frac{(ap,yp;p)_\infty}{(p,ayp;p)_\infty}\right] \quad (3.3)$$

$$\Phi\begin{bmatrix}x,y:ap,bp:cq,\frac{aq}{bc}; & \\ xyP:a:b:\frac{ap}{c},bcp:q,\frac{aq}{b}; & P,pq,\frac{p}{q},p,q;P\end{bmatrix}$$

$$+\Phi\begin{bmatrix}xP,yP:ap,bp:cq,\frac{aq}{bc}; & \\ xyP:a:b:\frac{ap}{c},bcp:q,\frac{aq}{b}; & P,pq,\frac{p}{q},p,q;q\end{bmatrix}$$

$$-\Phi\begin{bmatrix}x,y:apq:\frac{bp}{q}:a,b:c,\frac{a}{bc}; & \\ xyp:a:b:\frac{ap}{c,bcp:q,\frac{aq}{b};} & P,bq,\frac{p}{q}p,q;Pq\end{bmatrix}$$

$$=\frac{(xP,yP,;P)_\infty}{(P,xyP;P)_\infty}\frac{(ap,bp;p)_\infty}{(q,\frac{aq}{b};q)_\infty}\frac{(cq,\frac{aq}{bc};q)_\infty}{(\frac{ap}{c},bcp;p)_\infty} \quad (3.4)$$

## 4. Proof of Main Results

Now first we take $u_r = v_r = 1$ in (2.13) and (2.14) Bailey's transformation takes the following form:

If $\beta_n = \sum_{r=0}^{n}\alpha_r$ (4.1)

$\Upsilon_n = \sum_{r=n}^{\infty}\delta_r$

$\Upsilon_n = \sum_{r=0}^{\infty}\delta_{r+n}$ (4.2)

then $\sum_{n=0}^{\infty}\alpha_n\Upsilon_n = \sum_{n=0}^{\infty}\beta_n\delta_n$ (4.3)

By putting the value of $\beta_n$ and $\gamma_n$ above equation can be written as

$$\sum_{n=0}^{\infty}\alpha_n\sum_{r=0}^{\infty}\delta_r + \sum_{n=0}^{\infty}\alpha_n\delta_n$$

$$=\sum_{n=0}^{\infty}\delta_n\sum_{r=0}^{n}\alpha_r + \sum_{n=0}^{\infty}\alpha_n\sum_{r=0}^{n}\delta_r \quad (4.4)$$

Proof of result (3.1) Taking $\alpha_r = \frac{(\alpha,\beta;q)_r q^r}{(q,\alpha\beta q;q)_r}$ and $\delta_r = \frac{(a,y;p)_r p^r}{(p,ayp;p)_r}$ and putting the value of $\alpha_r$ and $\delta_r$ in (4.4) respectively, we get the following transformation:

$$\sum_{n=0}^{\infty}\frac{(\alpha,\beta;q)_n q^n}{(q,\alpha\beta q;q)_n}\sum_{r=0}^{\infty}\frac{(a,y;p)_r p^r}{(p,ayp;p)_r} + \sum_{n=0}^{\infty}\frac{(\alpha,\beta;q)_n q^n}{(q,\alpha\beta q;q)_n}\frac{(a,y;p)_n p^n}{(p,ayp;p)_n}$$

$$=\sum_{r=0}^{n}\frac{(\alpha,\beta;q)_r q^r}{(q,\alpha\beta q;q)_r} + \sum_{n=0}^{\infty}\frac{(\alpha,\beta;q)_n q^n}{(q,\alpha\beta;q)_n}\sum_{r=0}^{n}\frac{(a,y;p)_r p^r}{(p,ayp;p)_r} \quad (4.5)$$

Now using result (2.9) we get the following transformation:

$$\Phi\begin{bmatrix} a,y;\alpha q;\beta q;p,q;p \\ ayp;q,\alpha\beta q \end{bmatrix} - \Phi\begin{bmatrix} \alpha,\beta;a,y;q,p;pq \\ \alpha\beta q;p,ayp \end{bmatrix} + \Phi\begin{bmatrix} \alpha,\beta;ap,yp;q,p;q \\ \alpha\beta q;p,ayp \end{bmatrix}$$

$$= \left[\frac{(\alpha q,\beta q;q)_\infty}{(q,\alpha\beta q;q)_\infty}\right]\left[\frac{(ap,yp;p)_\infty}{(p,ayp;p)_\infty}\right]$$

Which on simplification gives the result (3.1)

Proof of result (3.2) Taking $\alpha_r = \frac{(\alpha,q\sqrt{\alpha},-q\sqrt{\alpha},\beta;q)_r}{(q,\sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta};q)_r}\beta^r$ *and* $\delta_r = \frac{(a,y;p)_r p^r}{(p,ayp;p)_r}$ and putting the value of $\alpha_r$ and $\delta_r$ in (4.4) respectively, we get the following transformation:

$$\sum_{n=0}^{\infty}\frac{(\alpha,q\sqrt{\alpha},-q\sqrt{\alpha},\beta;q)_n}{\left(q,\sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta};q\right)_n}\beta^n\sum_{r=0}^{\infty}\frac{(a,y;p)_r q^r}{(p,ayp;p)_r} + \sum_{n=0}^{\infty}\frac{(\alpha,q\sqrt{\alpha},-q\sqrt{\alpha},\beta;q)_n}{\left(q,\sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta};q\right)_n}\beta^n\frac{(a,y;p)_n p^n}{(p,ayp;p)_n} =$$

$$\sum_{n=0}^{\infty}\frac{(a,y;p)_n}{(p,ayp;p)_n}p^n\sum_{r=0}^{n}\frac{(\alpha,q\sqrt{\alpha},-q\sqrt{\alpha},\beta;q)_r}{\left(q,\sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta};q\right)_r}\beta^n\sum_{n=0}^{\infty}\frac{(\alpha,q\sqrt{\alpha},-q\sqrt{\alpha},\beta;q)_n}{\left(q,\sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta};q\right)_n}\beta^n\sum_{r=0}^{n}\frac{(a,y;p)_r p^r}{(p,ayp;p)_r}$$

Now using result (2.10) we get the following transformation:

$$\Phi\begin{bmatrix} \alpha q,\beta q;a,y;q,p;p\beta \\ \frac{\alpha q}{\beta};p,ayp \end{bmatrix} + \Phi\begin{bmatrix} \alpha,q\sqrt{\alpha},-q\sqrt{\alpha},\beta;ap,yp;q,p;q\beta \\ \sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta};p,ayp \end{bmatrix} - \Phi\begin{bmatrix} \alpha,q\sqrt{\alpha},-q\sqrt{\text{ã}},\beta;a,y;\beta p \\ \sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta};p,ayp \end{bmatrix}$$

$$= \left[\frac{(ap,yp;p)_\infty}{(p,ayp;p)_\infty}\right]\sum_{n=0}^{\infty}\frac{(\alpha,q\sqrt{\alpha},-q\sqrt{\alpha},\beta;q)_n}{(q,\sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta};q)_n}\beta^n$$

Which on simplification gives the result (3.2)

Proof of result (3.3) Taking $\alpha_r = \frac{(\alpha,q\sqrt{\alpha},-q\sqrt{\alpha},\beta,\gamma,\delta;q)_r q^r}{\left(q,\sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta},\frac{\alpha q}{\gamma},\frac{\alpha q}{\delta};q\right)_r}$ and $\delta_r = \frac{(a,y;p)_r p^r}{(p,ayp;p)_r}$ and putting the value of $\alpha_r$ and $\delta_r$ in (4.4) respectively, we get the following transformation:

$$\sum_{n=0}^{\infty}\frac{(\alpha,q\sqrt{\alpha},-q\sqrt{\alpha},\beta,\gamma,\delta;q)_n q^n}{\left(q,\sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta},\frac{\alpha q}{\gamma},\frac{\alpha q}{\delta};q\right)_n}\sum_{r=0}^{\infty}\frac{(a,y;p)_r p^r}{(p,ayp;p)_r} + \sum_{n=0}^{\infty}\frac{(\alpha,q\sqrt{\alpha},-q\sqrt{\alpha},\beta,\gamma,\delta;q)_n q^n}{\left(q,\sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta},\frac{\alpha q}{\gamma},\frac{\alpha q}{\delta};q\right)_n}\frac{(a,y;p)_n p^n}{(p,ayp;p)_n}$$

$$= \sum_{n=0}^{\infty}\frac{(a,y;p)_n p^n}{(p,ayp;p)_n}\sum_{r=0}^{\infty}\frac{(\alpha,q\sqrt{\alpha},-q\sqrt{\alpha},\beta,\gamma,\delta;q)_r q^r}{(q,\sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta},\frac{\alpha q}{\gamma},\frac{\alpha q}{\delta};q)_r} + \sum_{n=0}^{\infty}\frac{(\alpha,q\sqrt{\alpha},-q\sqrt{\alpha},\beta,\gamma,\delta;q)_n q^n}{\left(q,\sqrt{\alpha},-\sqrt{\alpha},\frac{\alpha q}{\beta},\frac{\alpha q}{\gamma},\frac{\alpha q}{\delta};q\right)_n}\sum_{r=0}^{n}\frac{(a,y;p)_r p^r}{(p,ayp;p)_r}$$

Now using result (2.11) we get the following transformation:

$$\Phi\begin{bmatrix} x,y:ap,bp:cq,\frac{aq}{bc}; & \\ xyP:a:b:\frac{ap}{c},bcp:q,\frac{aq}{b}; & P,pq,\frac{p}{q},p,q;P \end{bmatrix} + \Phi\begin{bmatrix} xP,yP:ap,bp:cq,\frac{aq}{bc}; & \\ xyP:a:b:\frac{ap}{c},bcp:q,\frac{aq}{b}; & P,pq,\frac{p}{q},p,q;q \end{bmatrix}$$

$$-\Phi\begin{bmatrix} x,y:apq:\frac{bp}{q}:a,b:c,\frac{a}{bc}; & \\ xyp:a:b:\frac{ap}{c,bcp:q,\frac{aq}{b};} & P,bq,\frac{p}{q}p,q;Pq \end{bmatrix}$$

$$= \frac{(xP,yP,;P)_\infty}{(P,xyP;P)_\infty}\frac{(ap,bp;p)_\infty}{(q,\frac{aq}{b};q)_\infty}\frac{(cq,\frac{aq}{bc};q)_\infty}{(\frac{ap}{c},bcp;p)_\infty}$$

Which on simplification gives the result (3.3)

Proof of result (3.4) Taking $\alpha_r = (apq;pq)_r(\frac{bp}{q};\frac{p}{q})_r(a,b;p)_r(c,\frac{a}{bc};q)_r q^r{}_/(a;pq)_r(b;\frac{p}{q})_r(q,\frac{aq}{b};q)_r(\frac{ap}{c},bcp;p)_r$ and

$\delta_r = \frac{(x,y;P)_r P^r}{(P,xyP;P)r}$ and putting the value of $\alpha_r$ and $\delta_r$ in (3.4) respectively, we get the following transformation:

Now using result (2.12) we get the following transformation:

$$\Phi\left[\begin{matrix} x, y: ap, bp: cq, \frac{aq}{bc}; \\ xyP: a: b: \frac{ap}{c}, bcp: q, \frac{aq}{b}; \end{matrix} P, pq, \frac{p}{q}, p, q; P\right]$$

$$+\Phi\left[\begin{matrix} xP, yP: ap, bp: cq, \frac{aq}{bc}; \\ xyP: a: b: \frac{ap}{c}, bcp: q, \frac{aq}{b}; \end{matrix} P, pq, \frac{p}{q}, p, q; q\right]$$

$$-\Phi\left[\begin{matrix} x, y: apq: \frac{bp}{q}: a, b: c, \frac{a}{bc}; \\ xyp: a: b: \frac{ap}{c, bcp: q, \frac{aq}{b};} \end{matrix} P, bq, \frac{p}{q}p, q; Pq\right]$$

$$= \frac{(xP, yP,; P)_\infty}{(P, xyP; P)_\infty} \frac{(ap, bp; p)_\infty}{(q, \frac{aq}{b}; q)_\infty} \frac{(cq, \frac{aq}{bc}; q)_\infty}{(\frac{ap}{c}, bcp; p)_\infty}$$

Which on simplification gives the result (3.4)

## 5. Special cases

1. Replacing p = q in (3.1) we obtain

$${}_4\Phi_3\left[\begin{matrix} \alpha, y; \alpha q, \beta q; q; q \\ ayq; q, \alpha\beta q \end{matrix}\right] - {}_4\Phi_3\left[\begin{matrix} \alpha, \beta; a, y; q; q^2 \\ \alpha\beta q; q, ayq \end{matrix}\right] + {}_4\Phi_3\left[\begin{matrix} \alpha, \beta; aq, yq; q; q \\ \alpha\beta q; q, ayq \end{matrix}\right]$$

$$= \left[\frac{(\alpha q, \beta q; q)_\infty}{(q, \alpha\beta q; q)_\infty}\right] \left[\frac{(aq, yq; q)_\infty}{(q, ayq; q)_\infty}\right]$$

Replacing $p = q$ in (3.2) we obtain

$${}_4\Phi_3\left[\begin{matrix} \alpha q, \beta q; a, y; q; q\beta \\ \frac{\alpha q}{\beta}; q, ayq \end{matrix}\right] + {}_4\Phi_3\left[\begin{matrix} \alpha, q\sqrt{\alpha}, -q\sqrt{\alpha}, \beta; aq, yq; q; q\beta \\ \sqrt{\alpha}, -\sqrt{\alpha}, \frac{\alpha q}{\beta}; q, ayq \end{matrix}\right]$$

$$-{}_4\Phi_3\left[\begin{matrix} \alpha, q\sqrt{\alpha}, -q\sqrt{\text{ā}}, \beta; a, y; \beta q \\ \sqrt{\alpha}, -\sqrt{\alpha}, \frac{\alpha q}{\beta}; q, ayq \end{matrix}\right] = \left[\frac{(aq, yq; q)_\infty}{(q, ayq; q)_\infty}\right] \sum_{n=0}^{\infty} \frac{(\alpha, q\sqrt{\alpha}, -q\sqrt{\alpha}, \beta; q)_n}{(q, \sqrt{\alpha}, -\sqrt{\alpha}, \frac{\alpha q}{\beta}; q)_n} \beta^n$$

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